IDO-17078
July 1965

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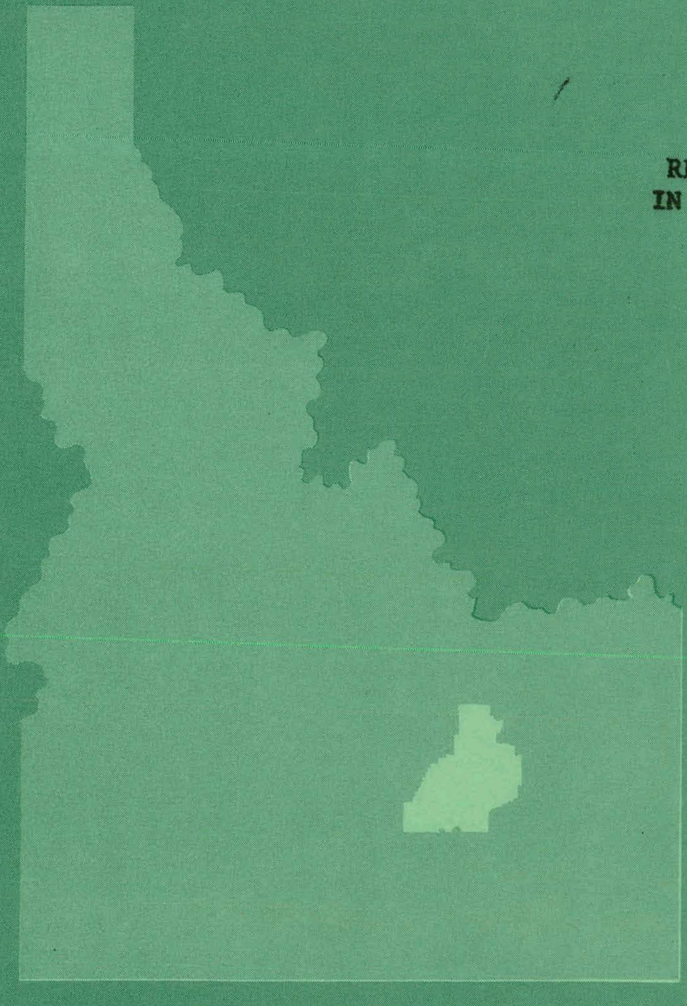

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IDO-17078
AEC Research and Development Report
Reactor Technology
TID-4500 (41st Ed.)
Issued: July 1965

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A SYSTEM FOR PROCESSING REACTOR TRANSIENT DATA ON THE IBM-7040 COMPUTER

by

B. J. Power

R. N. Hagen

S. O. Johnson

PHILLIPS
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Atomic Energy Division
Contract AT(10-1)-205
Idaho Operations Office
U. S. ATOMIC ENERGY COMMISSION

ACKNOWLEDGMENTS

The authors would like to express their appreciation to G. A. Cazier and T. O. Elsethagen for their assistance in computer methods and programming.

ABSTRACT

To facilitate the processing and analysis of data recorded during transient tests in the Spert reactors, a system of programs for the IBM-7040 computer has been developed to (a) smooth and store data so they are readily accessible, (b) calculate from the power history the reactivity and energy release as functions of time, and (c) provide a means by which frequency response analyses of data can be made. This report describes the mathematics employed in the various programs in the system and the procedures necessary to process data with the system. Test and sample problems are presented, and a complete listing of the source program is included.

CONTENTS

FIGURES

SPORT

A SYSTEM FOR PROCESSING REACTOR TRANSIENT DATA ON THE IBM-7040 COMPUTER

I. INTRODUCTION

SPORT (System for Processing Reactor Transient Data) is a combination of IBM-7040 computer programs which have been developed for the routine processing of transient data obtained from the Spert reactors. The system consists of three programs, SMOOTH [1], REACTIVITY [2], and FREQUENCY RESPONSE [3], originally developed for the IBM-7040 computer, and routines for the initial preparation of the raw data.

The data preparation section of SPORT contains routines to (a) normalize and shift the input data, (b) compute the natural logarithm of the data, and (c) composite data from several differently scaled channels into a single data trace.

The SMOOTH program is used to eliminate noise from the input data. The program is, in effect, an adjustable low-pass filter having a sharp cut-off characteristic. Data may be automatically recirculated through the SMOOTH program in order to achieve the desired degree of smoothing. The technique used in the program also yields the smoothed first derivative of the input data.

The REACTIVITY program is used to derive the reactivity as a function of time from the power history of a reactor. The energy release is also calculated by this program. Input data for this program must first be processed by the SMOOTH program.

The FREQUENCY RESPONSE program is used to calculate the ratio of the unilateral Fourier transforms of two input variables. This program was written primarily for the purpose of obtaining the frequency response of a linear system from the transient response of the system.

The programs contained in SPORT are normally used in sequence such that the output of one program is used as input to another. Although the programs can be used separately, SPORT normally provides for the automatic sequencing of the programs. This feature has eliminated much of the manual data handling formerly required to process transient reactor data.

This report presents descriptions of the mathematical methods used in each program in SPORT and instructions in the mechanics of processing data with the system. Section II contains a discussion of options available for initial data preparation and a description of the calculational procedure used in each of the three programs, SMOOTH, REACTIVITY, and FREQUENCY RESPONSE. Section III, a description of the input format, is presented in three subsections:

(1) The processing options which are available to the user

(2) The necessary control cards

(3) The control card sequence.

Section IV contains a description of the output formats of the various programs and examples of each type of output. Section V presents some sample problems which illustrate the use of SPORT. In Section VI, problems which have been used to test various portions of the system are described. In Section VII, computer operating times are estimated. Proofs of some theorems used in Section II, listings of the source programs, a listing of a program to prepare data for input to SPORT, and a listing of a program to read a binary tape produced with SMOOTH are contained in the appendixes.

II. PROGRAM LOGIC AND MATHEMATICS

1. DATA PREPARATION

Due to the nature of data which may be processed by SPORT and the various processes which may be applied to data, it is necessary to provide a means for initial data preparation. Data preparation is accomplished before entering the major programs (SMOOTH, REACTIVITY, and FREQUENCY RESPONSE) and may be considered in three phases: (a) normalization and shifting of data, (b) compositing data recorded from several channels into one data trace, and (c) calculation of the natural logarithm of the data.

A routine for normalizing and shifting data is provided in order to convert raw data into physical units and to aid in the formation of composite traces from several differently scaled data channels. Normalization and shifting of data is accomplished by a simple linear transformation of the form

$$X_\gamma = \gamma X + s \tag{1}$$

where $X \equiv$ input data point (either abscissa or ordinate)

$\gamma \equiv$ normalizing coefficient

$s \equiv$ data shift

$X_\gamma \equiv$ normalized and shifted point.

Of particular interest in data preparation is the problem of compositing data from several channels into one data trace which covers a wide range of values. For example, in power transients where the power may vary from an initial value of a few watts to hundreds of megawatts, several instruments covering various ranges of data must be used in recording the data. Data recorded on the low range instruments (which saturate early in the transient) must be fitted to the data obtained from the higher range instruments so that one trace of data covering the entire transient is obtained. To form a good composite data trace from two data channels, it is necessary that both the overlapping data points and the slopes of the curves very nearly correspond. To form a composite trace, the data values which are to overlap in the composite channel are plotted; the normalizing and shifting coefficients required to make data values correspond are determined; and the data are adjusted according to Equation (1). No means are provided for correcting errors in the slope of data since such an error generally indicates nonlinearities in the recording instrument. Hence, a general method for correcting errors in slope cannot be devised.

As discussed in Section II-3, power data for calculating reactivity must be in logarithmic form when used as input to the REACTIVITY program. Since power data may not be recorded in logarithmic form, it is necessary to provide a means by which the logarithm of data may be calculated. A standard subroutine for evaluating the natural logarithm of data is used. If a logarithm to another base is desired, it may be obtained through the use of the normalizing coefficient; ie,

$$\log_m x = \left(\log_m e\right)\left(\log_e x\right) . \tag{2}$$

2. THE SMOOTH PROGRAM

2.1 Introduction

The SMOOTH program was written primarily for the purpose of removing noise from digitized experimental data. Briefly, the technique used in SMOOTH is that of least-squares fitting of parabolas to sections of input data. In general, a parabola is fitted to the first n data points (where n is designated by the user), and one smoothed point is taken from this parabola. The second smoothed point is obtained by fitting a parabola to the second through the n + 1 data point, the third smoothed point by fitting to the third through the n + 2 data point, and so on. The smoothed data generated by the program are given at equal time increments. It is not necessary, however, that the input data be given at equal time increments.

2.2 Solution of Equations

The process used in the SMOOTH program is illustrated in Figure 1. In Figure 1, input data points, $[t_i, f(t_i)]$, $[t_{i+1}, f(t_{i+1})]$, . . . , $[t_{i+5}, f(t_{i+5})]$, are represented by x's; and smoothed data points, $[\tau_j, F_j(\tau_j)]$ and $[\tau_{j+1}, F_{j+1}(\tau_{j+1})]$, are represented by circles. It should be noted that the time value of the output points, τ_j and τ_{j+1}, may not necessarily correspond with any input time point. The first parabola, $F_j(\tau)$, is obtained by a least-squares fitting of a parabola to the five data points, $f(t_i)$, $f(t_{i+1})$, . . . , $f(t_{i+4})$. These points are used since τ_j is "centered" (as defined below) among the time points t_i, t_{i+1}, . . . , t_{i+4}. The smoothed value is obtained by evaluating $F_j(\tau_j)$. The time point τ_{j+1} is centered among the points t_{i+1}, t_{i+2}, . . . , t_{i+5}; so this smoothed point is obtained by fitting a parabola $F_{j+1}(\tau)$ to $f(t_{i+1})$, $f(t_{i+2})$, . . . , $f(t_{i+5})$ and evaluating

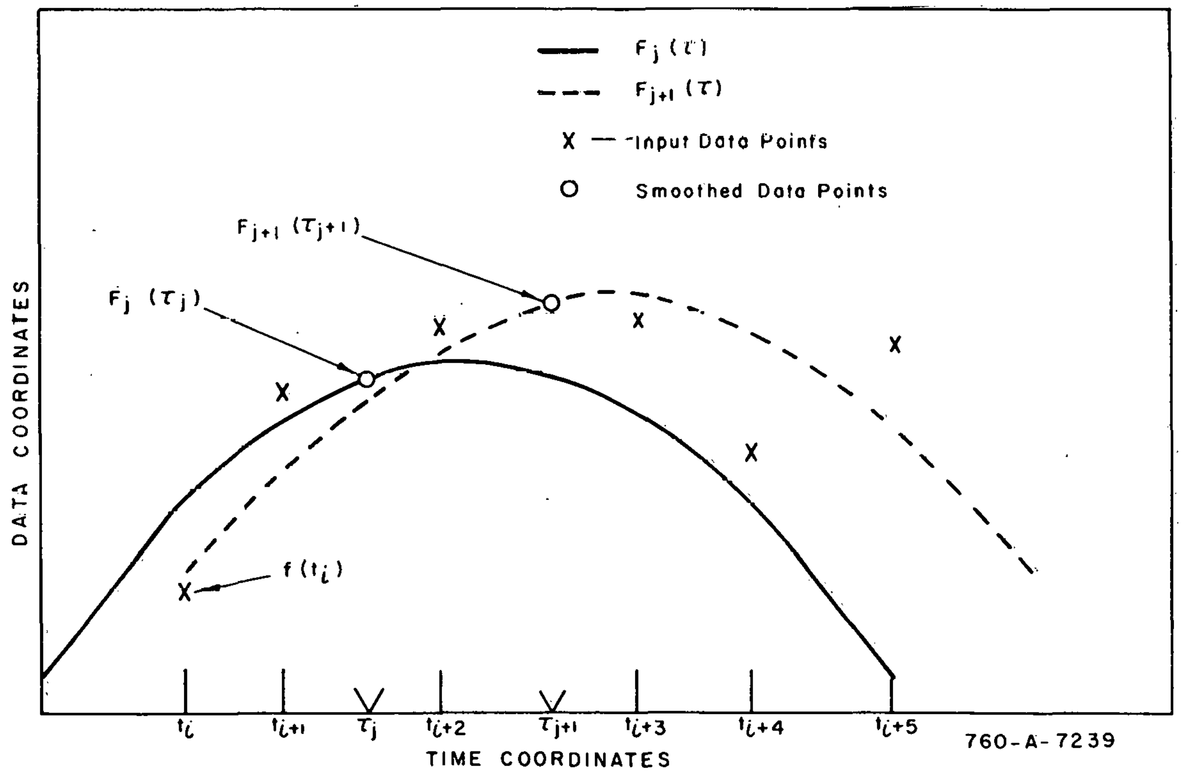

Fig. 1 Process used in the SMOOTH program.

$F_{j+1}(\tau_{j+1})$. The definition of the expression "centered", the method of least-squares fitting of a parabola to n data points, a description of a time shift employed in SMOOTH to increase its accuracy, and the equations which are solved in the program are discussed in detail in the following paragraphs.

The symbol, t_i, in this discussion, used to represent time values of input data points while the symbol, τ_j, is used to represent time values of the smoothed data points. (The problem is complicated by the fact that there may be time shifts in either or both of the time scales; but in this discussion, reference is made only to time values corresponding to the time scale on the input data.) In using the program, τ_o, the time point at which the first smoothed point is desired must be furnished as an input parameter. Data time points, t_i, t_{i+1}, . . . , t_{i+m} are then found so that τ_o is centered among these points. The definition of centered, then, is that

$$\tfrac{1}{2}[t_{i+\frac{1}{2}m-1} + t_{i+\frac{1}{2}m}] < \tau_o \leq \tfrac{1}{2}[t_{i+\frac{1}{2}m} + t_{i+\frac{1}{2}m+1}] \tag{3}$$

(In this case, smoothing is on m + 1 points; so it is apparent from Equation (3) that smoothing must always be on an odd number of points.) A parabola is fitted to the data values $f(t_i)$, $f(t_{i+1})$, . . . , $f(t_{i+m})$; and the smoothed value is taken to be the value of the parabola at the point, τ_o. The time step, $\Delta\tau$, is then added to τ_o; ie,

$$\tau_1 = \tau_o + \Delta\tau \tag{4}$$

and the process is repeated.

To determine a least-squares fit of a function, g(x), to points $h(x_1)$,$h(x_2)$, . . . , $h(x_n)$, it is necessary to find the parameters of g(x) which make the sum

$$\sum_{k=1}^{n} [h(x_k) - g(x_k)]^2$$

a minimum. In the case of the SMOOTH program, the problem is to fit a parabola to a given number of data points, say n. If the parabola is written

$$F(t) = at^2 + bt + c \tag{5}$$

then it is necessary to minimize the sum

$$v^2(a,b,c) = \sum_{k=1}^{n} [f(t_{i+k}) - at^2_{i+k} - bt_{i+k} - c]^2 \quad . \tag{6}$$

This function will be a minimum when

$$\frac{\partial v^2}{\partial a} = \frac{\partial v^2}{\partial b} = \frac{\partial v^2}{\partial c} = 0 \quad . \tag{7}$$

Equations (6) and (7) reduce to the matrix equation

$$\begin{bmatrix} n & \Sigma t_{i+k} & \Sigma t^2_{i+k} \\ \Sigma t_{i+k} & \Sigma t^2_{i+k} & \Sigma t^3_{i+k} \\ \Sigma t^2_{i+k} & \Sigma t^3_{i+k} & \Sigma t^4_{i+k} \end{bmatrix} \begin{bmatrix} c \\ b \\ a \end{bmatrix} = \begin{bmatrix} \Sigma f(t_{i+k}) \\ \Sigma f(t_{i+k})\ t_{i+k} \\ \Sigma f(t_{i+k})\ t^2_{i+k} \end{bmatrix} \qquad (8)$$

or

$$T \cdot S = P \qquad (9)$$

where

$$\Sigma = \sum_{k=1}^{n}$$

and T, S, and P are the matrices in Equation (8). The problem, then, reduces to one of matrix inversion where

$$S = T^{-1} \cdot P \qquad (10)$$

It should be noted that the matrix, T, is dependent only upon time; and that in certain time intervals, poor accuracy is obtained in evaluating T^{-1}. To improve the accuracy of this calculation, a time shift is employed in SMOOTH so that the time used in the calculation is equal to the time of the data point minus τ_j, the time point at which the smoothed value is to be calculated. This shifts the time values, $t_{i+1}, \ldots, t_{i+n}$, to points near the origin and maintains better accuracy in the calculation of T^{-1}. Figure 2 illustrates this time shift. The coefficients calculated by SMOOTH at a time point, τ_j, say A_j, B_j, C_j, are related to the coefficients a_j, b_j, and c_j given by Equation (10) by the following equation:

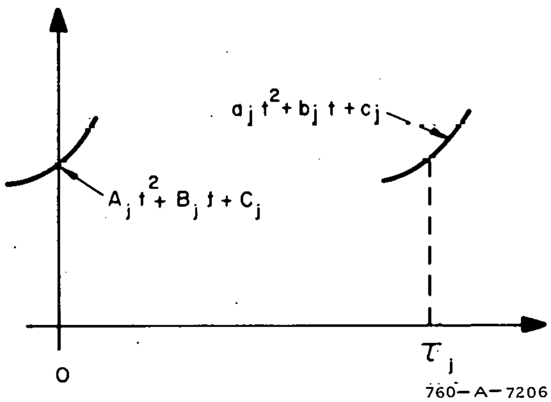

Fig. 2 Time shift used in the SMOOTH program.

$$A_j t^2 + B_j t + C_j = a_j(t + \tau_j)^2 + b_j(t + \tau_j) + c_j \qquad (11)$$

Therefore, C_j is the smoothed data value at τ_j, and B_j is the slope of the smoothed function at τ_j.

With the time shift described above, the time matrix becomes

$$\bar{T}_j = \begin{bmatrix} n & \Sigma(t_k-\tau_j) & \Sigma(t_k-\tau_j)^2 \\ \Sigma(t_k-\tau_j) & \Sigma(t_k-\tau_j)^2 & \Sigma(t_k-\tau_j)^3 \\ \Sigma(t_k-\tau_j)^2 & \Sigma(t_k-\tau_j)^3 & \Sigma(t_k-\tau_j)^4 \end{bmatrix} \tag{12}$$

and the coefficients A_j, B_j, C_j are given by the matrix equation

$$\bar{S}_j = \bar{\bar{T}}_j^{-1} \cdot P \quad . \tag{13}$$

A case of special interest is that of data points at constant time intervals, Δt. In this case,

$$\Sigma(t_k-\tau_j) = \Delta t \sum_{-\frac{1}{2}(n-1)}^{\frac{1}{2}(n-1)} k = 0 \tag{14}$$

$$\Sigma(t_k-\tau_j)^2 = 2\Delta t^2 \sum_{1}^{\frac{1}{2}(n-1)} k^2 \equiv K_1 \tag{15}$$

$$\Sigma(t_k-\tau_j)^3 = \Delta t^3 \sum_{-\frac{1}{2}(n-1)}^{\frac{1}{2}(n-1)} k^3 = 0 \tag{16}$$

$$\Sigma(t_k-\tau_j)^4 = 2\Delta t^4 \sum_{1}^{\frac{1}{2}(n-1)} k^4 \equiv K_2 \quad . \tag{17}$$

Equation (12) then becomes

$$\bar{T} = \begin{bmatrix} n & 0 & K_1 \\ 0 & K_1 & 0 \\ K_1 & 0 & K_2 \end{bmatrix} \tag{18}$$

and

$$C_j = \frac{1}{K_1(nK_2-K_1^2)} [K_2\Sigma f(t_{i+k}) - K_1\Sigma f(t_{i+k})\, t_k^{*2}] \tag{19}$$

$$B_j = \frac{1}{K_1} \Sigma f(t_{i+k})\, t_k^{*} \tag{20}$$

$$A_j = \frac{1}{nK_2 - K_1^2} [n\Sigma f(t_{i+k})\ t_k^{*2} - K_1 \Sigma f(t_{i+k})] \tag{21}$$

where

$$t_k^* = t_{i+k} - \tau_j \quad . \tag{22}$$

For data points at constant time intervals, considerable computer time can be saved by using Equations (19), (20), and (21).

The output from SMOOTH consists of a listing of the identification number, the time values, and the coefficients A, B, and C (corresponding to a parabola, $F(t) = At^2 + Bt + C$) and plots of the coefficients B and C. It should be recalled from the above discussion that these coefficients correspond to a parabola fitted to data points centered about the origin (as shown in Figure 3). The smoothed data value is evaluated as F(0) which reduces to the value of coefficient C. Therefore, the parameter labeled coefficient C, both in the listings and in the plots, represents the smoothed data values. In a similar manner, the derivative of F(t) evaluated at t = 0 is the derivative of the smoothed data (and an approximation of the derivative of the original data) at each output point. But the derivative of F(t) evaluated at t = 0 is simply the coefficient B. Therefore, in output from the SMOOTH program and in subsequent discussions in this report, the coefficients C and B are used to represent the smoothed data values and the derivative of the smoothed data values, respectively.

2.3 Filter Characteristics of the SMOOTH Program

The primary objective of the SMOOTH program is to reduce the noise in the input data without significantly distorting the "signal". In order to properly apply the SMOOTH program to a given set of data points, it is quite helpful to have available the characteristics of the program normally associated with filters; ie, the impulse response, the step response, and the frequency response. These characteristics are derived and discussed in this section.

It should be noted that the SMOOTH program differs from ordinary or "physically realizable" filters in two respects: (a) The time span of the input data considered in determining the output is finite. (b) The output at a particular time is determined from future as well as past input data. That is, while in an ordinary filter use of future data is not possible and all past data is theoretically considered in determining the output, in the SMOOTH program a finite range of both past and future data is used to determine the output.

In the following derivations, two assumptions are utilized. First, it is assumed that the past and future time spans of data considered by the program are equal. This assumption is valid only for input data which are digitized at equal time increments. Second, for mathematical convenience, it is assumed that the input data are continuous rather than discrete. This assumption is equivalent to assuming that the discrete data points are of sufficient density to provide an accurate representation of the initially continuous data. Thus, the results of this section apply only to input data which have been digitized at equal time increments and for which the digitizing interval is such that the digitized data are an accurate representation of the initial (continuous) data.

The method of filtering used in the SMOOTH program is to approximate the input data, f(t), by a function of the form,

$$F(t) = a(t)t^2 + b(t)t + c(t)$$

where a(t), b(t), and c(t) are defined such that

$$v^2(t) = \frac{1}{\delta t} \int_{t-\frac{\delta t}{2}}^{t+\frac{\delta t}{2}} \left\{ f(\tau) - [a(t)\tau^2 + b(t)\tau + c(t)] \right\}^2 d\tau \tag{23}$$

is minimized. Equation (23) can be rewritten as

$$v^2(t) = \frac{1}{\delta t} \int_{t-\frac{\delta t}{2}}^{t+\frac{\delta t}{2}} \left\{ f(\tau) - [A(t) \{\tau - t\}^2 + B(t) \{\tau - t\} + C(t)] \right\}^2 d\tau \tag{24}$$

where

$$A(t) = a(t) \tag{25}$$

$$B(t) = b(t) + 2a(t)t \tag{26}$$

and

$$C(t) = a(t)t^2 + b(t)t + c(t) \quad . \tag{27}$$

Note that, as indicated by Equation (27),

$$C(t) = F(t) . \tag{28}$$

Hence,

$$\frac{dF(t)}{dt} - t^2 \frac{da}{dt} + 2at + t \frac{db}{dt} + b + \frac{dc}{dt} \tag{29}$$

or, by Equation (26),

$$\frac{dF(t)}{dt} = t^2 \frac{da}{dt} + t \frac{db}{dt} + \frac{dc}{dt} + B \quad . \tag{30}$$

In using the output of the SMOOTH program, the coefficient B is taken as an approximation to dF(t)/dt. This approximation is reasonable since in the actual input to SMOOTH, the function f(t) is represented by a set of discrete points. Between points the function is approximated by the appropriate parabola so that in the immediate vicinity of a point, the coefficients a, b, and c are constant. The consequences of the approximation

$$\frac{dF(t)}{dt} \approxeq B(t)$$

are discussed later in the development of the frequency response of SMOOTH.

In order to minimize v^2 (t), it is necessary that

$$\frac{\partial v^2}{\partial A} = 0, \ \frac{\partial v^2}{\partial B} = 0, \ \text{and} \ \frac{\partial v^2}{\partial C} = 0 \quad .$$

Thus, from Equation (24),

$$\frac{\partial v^2}{\partial A} = -\frac{2}{\delta t}\int_{t-\frac{\delta t}{2}}^{t+\frac{\delta t}{2}} \left\{f(\tau) - [A\{\tau-t\}^2 + B\{\tau-t\} + C]\right\}\{\tau-t\}^2\, d\tau = 0 \quad (31)$$

$$\frac{\partial v^2}{\partial B} = -\frac{2}{\delta t}\int_{t-\frac{\delta t}{2}}^{t+\frac{\delta t}{2}} \left\{f(\tau) - [A\{\tau-t\}^2 + B\{\tau-t\} + C]\right\}\{\tau-t\}\, d\tau = 0 \quad (32)$$

and

$$\frac{\partial v^2}{\partial C} = -\frac{2}{\delta t}\int_{t-\frac{\delta t}{2}}^{t+\frac{\delta t}{2}} \left\{f(\tau) - [A\{\tau-t\}^2 + B\{\tau-t\} + C]\right\} d\tau = 0 \quad . \quad (33)$$

Then, for Equation (31),

$$\frac{\delta t^5}{2^4 . 5} A(t) + \frac{\delta t^3}{2^2 . 3} C(t) = I_2(t) \quad (34)$$

from Equation (32),

$$\frac{\delta t^3}{2^2 . 3} B(t) = I_1(t) \quad (35)$$

and from Equation (33),

$$\frac{\delta t^3}{2^2 . 3} A(t) + \delta t C(t) = I_0(t) \quad (36)$$

where

$$I_2(t) = \int_{t-\frac{\delta t}{2}}^{t+\frac{\delta t}{2}} f(\tau)\, [\tau-t]^2\, d\tau \quad (37)$$

$$I_1(t) = \int_{t-\frac{\delta t}{2}}^{t+\frac{\delta t}{2}} f(\tau)\, [\tau-t]\, d\tau \quad (38)$$

and

$$I_0(t) = \int_{t-\frac{\delta t}{2}}^{t+\frac{\delta t}{2}} f(\tau)\, d\tau \quad . \quad (39)$$

Simultaneous solution of Equations (34), (35), and (36) yields

$$C(t) = \frac{9}{4\delta t} I_0 - \frac{15}{\delta t^3} I_2 \tag{40}$$

[where $C(t) = F(t)$].

and

$$B(t) = \frac{12}{\delta t^3} I_1 \tag{41}$$

[where $B(t) \simeq \frac{dF(t)}{dt}$].

2.31 Impulse Response. If the input function f(t) is a unit impulse at t = 0,

$$I_0 = \int_{t-\frac{\delta t}{2}}^{t+\frac{\delta t}{2}} u_1(\tau)\, d\tau = u(t + \frac{\delta t}{2}) - u(t - \frac{\delta t}{2}) \tag{42}$$

and

$$I_2 = \int_{t-\frac{\delta t}{2}}^{t+\frac{\delta t}{2}} (\tau-t)^2\, u_1(\tau)\, d\tau = t^2 \left[u(t + \frac{\delta t}{2}) - u(t - \frac{\delta t}{2})\right] \quad . \tag{43}$$

Substituting Equations (42) and (43) into Equation (40) yields for the impulse response of the SMOOTH program,

$$C(t) = \frac{9}{4\delta t} - \frac{15}{\delta t^3} t^2 \left[u(t + \frac{\delta t}{2}) - u(t - \frac{\delta t}{2})\right] \quad . \tag{44}$$

The anticipatory and finite memory characteristics are clearly illustrated by the sketch of the impulse response given in Figure 3. The input impulse is "anticipated" for $t > -\frac{\delta t}{2}$, but is "forgotten" when $t > \frac{\delta t}{2}$. In contrast an ordinary filter has no anticipatory properties, but in theory will "remember" the impulse forever.

2.32 The Step Response. If a unit step function is applied to the SMOOTH program at t = 0,

$$\begin{aligned} I_0 &= \int_{t-\frac{\delta t}{2}}^{t+\frac{\delta t}{2}} u(\tau)\, d\tau \\ &= t\left[u(t+\frac{\delta t}{2}) - u(t-\frac{\delta t}{2})\right] \\ &+ \frac{\delta t}{2}\left[u(t+\frac{\delta t}{2}) + u(t-\frac{\delta t}{2})\right] \end{aligned} \tag{45}$$

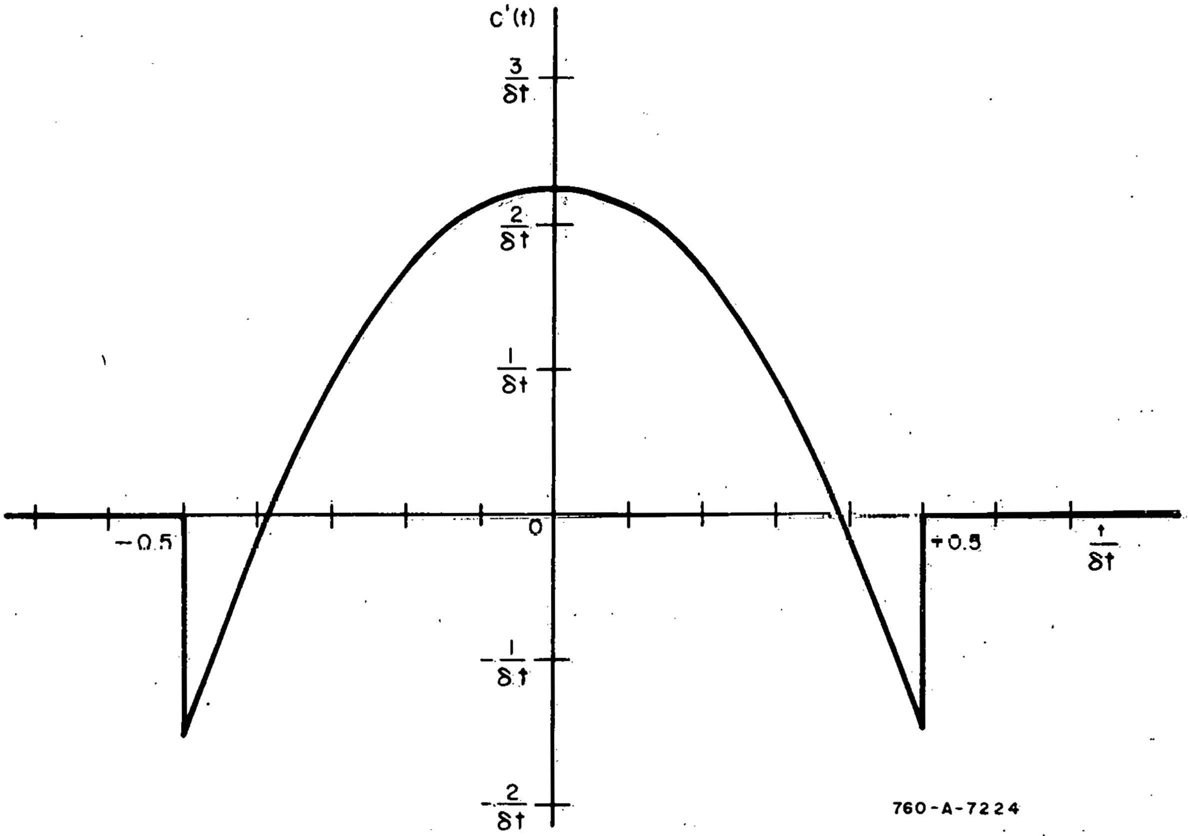

Fig. 3 Response of SMOOTH to the impulse function.

and

$$I_2 = \int_{t-\frac{\delta t}{2}}^{t+\frac{\delta t}{2}} (\tau - t)^2 \, u(\tau) \, d\tau$$

$$= \frac{t^3}{3} \left[u(t+\frac{\delta t}{2}) - u(t-\frac{\delta t}{2}) \right]$$

$$+ \frac{t^3}{24} \left[u(t+\frac{\delta t}{2}) + u(t-\frac{\delta t}{2}) \right] \quad . \qquad (46)$$

Substituting Equations (45) and (46) into Equation (40) and rearranging yields for the step response of the SMOOTH program,

$$C(t) = \left[\frac{9}{4\delta t} t - \frac{5}{\delta t^3} t^3 \right] \left[u(t + \frac{\delta t}{2}) - u(t - \frac{\delta t}{2}) \right]$$

$$+ \frac{1}{2} \left[u(t + \frac{\delta t}{2}) + u(t - \frac{\delta t}{2}) \right] \quad . \qquad (47)$$

As shown in Figure 4, the step response overshoots the magnitude of the applied step by about 8 percent. However for time greater than $\frac{\delta t}{2}$, the output is precisely equal to the magnitude of the applied step.

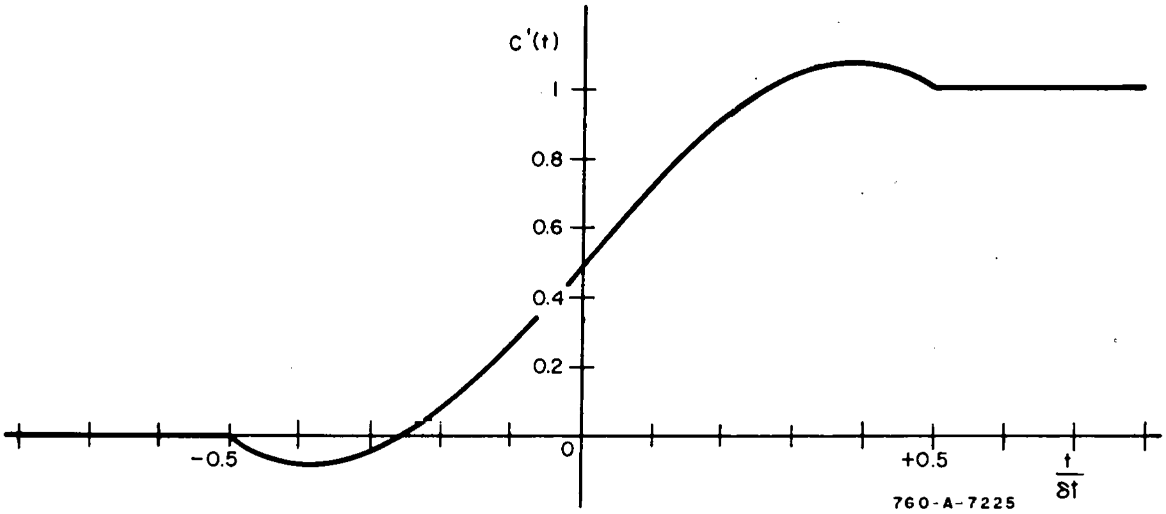

Fig. 4 Response of SMOOTH to the unit step function.

2.33 Frequency Response. The frequency response of the SMOOTH program may be derived by the common procedure of obtaining the Laplace transform of the impulse response. However, the procedure must be slightly altered because of the anticipatory nature of the SMOOTH program response. Since the ordinary Laplace transformation is unilateral, negative values of time cannot be considered. Therefore, in order to obtain the Laplace transform of the impulse response, it is necessary to apply the impulse at a time such that no response is obtained for times less than zero, ie, at $t \geq \frac{\delta t}{2}$.

Thus, let the input function, f(t), be a unit impulse at $t = \frac{\delta t}{2}$, ie,

$$f(t) = u_1 \left(t - \frac{\delta t}{2}\right) \quad .$$

Tho transfer function is then

$$G(s) = \frac{\overline{C}(s)}{\overline{u}_1(s)} \tag{48}$$

where $\overline{C}(s)$ is the Laplace transform of the response to a unit impulse $u_1(t - \frac{\delta t}{2})$. From Equation (44),

$$C\left(t - \frac{\delta t}{2}\right) = \left[\frac{9}{4\delta t} - \frac{15}{\delta t^3}\left(t - \frac{\delta t}{2}\right)^2\right]\left[u(t) - u(t - \delta t)\right] \tag{49}$$

Then,

$$\begin{aligned} \overline{C}(s) &= L\left[C\left(t - \frac{\delta t}{2}\right)\right] \\ &= \frac{15}{\delta t^2 s^2}\left[1 + e^{-\delta t s}\right] \\ &\quad - \left[\frac{3}{2\delta t s} + \frac{30}{\delta t^3 s^3}\right]\left[1 - e^{-\delta t s}\right] \end{aligned} \tag{50}$$

and

$$\bar{u}_1(s) = L\left[u\left(t - \frac{\delta t}{2}\right)\right] = e^{-\frac{\delta t}{2}s} . \tag{51}$$

Substituting Equations (50) and (51) into Equation (48) and rearranging yields for the transfer function of SMOOTH:

$$G(s) = \frac{15}{\delta t^2 s^2}\left[e^{\frac{\delta t}{2}s} + e^{-\frac{\delta t}{2}s}\right] - \left[\frac{3}{2\delta t s} + \frac{30}{\delta t^3 s^3}\right]\left[e^{\frac{\delta t}{2}s} - e^{-\frac{\delta t}{2}s}\right] . \tag{52}$$

The frequency response may be obtained by the usual procedure of setting $s = j\omega$. Thus, from Equation (52),

$$G(j\omega) = -\frac{15}{\delta t^2 \omega^2}\left[e^{j\frac{\delta t\omega}{2}} + e^{-j\frac{\delta t\omega}{2}}\right] - \left[\frac{3}{2j\delta t\omega} - \frac{30}{j\delta t^3\omega^3}\right]\left[e^{j\frac{\delta t\omega}{2}} - e^{-j\frac{\delta t\omega}{2}}\right] \tag{53}$$

or

$$G(j\omega) = -\frac{30}{\delta t^2\omega^2}\cos\frac{\delta t\omega}{2} - \left[\frac{3}{\delta t\omega} - \frac{60}{\delta t^3\omega^3}\right]\sin\frac{\delta t\omega}{2} . \tag{54}$$

It can easily be determined from Equation (54) that the frequency response, $G(j\omega)$, is always real and has an infinite number of zeros located on the positive real axis of the complex plane. It is positive in the frequency range between $\omega = 0$ and the first zero of $G(j\omega)$, negative between the first and second zeros, positive between the second and third zeros, etc. Further, it can be shown that

$$\lim_{\omega \to 0} G(j\omega) = 1$$

Thus, the SMOOTH program is a zero-phase, low-pass filter. It has an attenuation of 0.7 (3dB) at $\omega\delta t \approx 6.6$.

As shown in Figure 5, the roll-off characteristic preceding the first zero is rather sharp; but the effectiveness of the SMOOTH program in filtering high frequencies is reduced by the lobes between successive zeros. As discussed in a following subsection, however, the attenuation of high frequencies can be

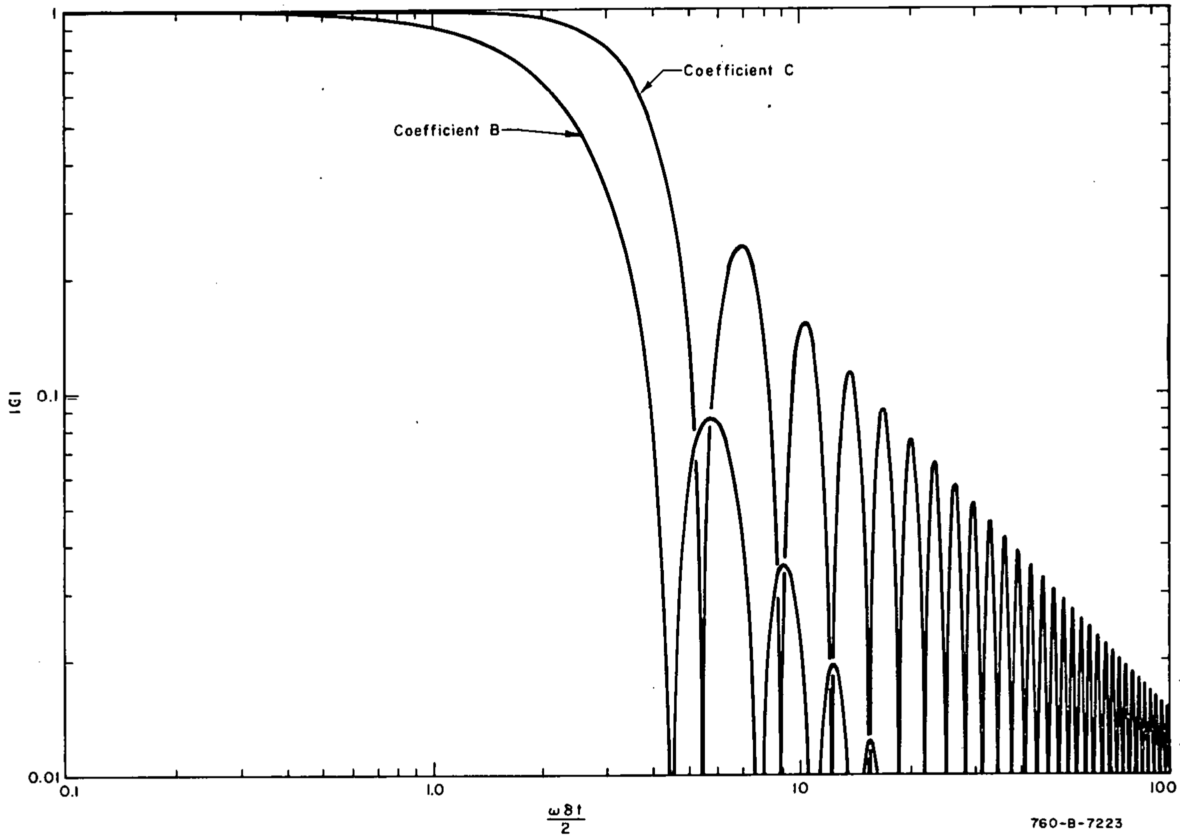

Fig. 5 Frequency response of SMOOTH for coefficients C and B.

markedly increased by multiple smoothing without significantly altering the low frequency transfer function.

Because the SMOOTH program automatically computes a smoothed derivative of the input data and because this derivative is used in the REACTIVITY program, the transfer function which is, in effect, applied to the derivative of the input data is also of interest. If B(t) is an approximation to df(t)/dt, then the transfer function of interest is

$$G'(s) = \frac{\overline{B}(s)}{s\overline{f}(s)} \qquad (55)$$

where $\overline{B}(s)$ is the transform of the B(t) which results when f(t) is applied. The transfer function, G'(s), is then a measure of the deviation of B(t) from df(t)/dt. If, as before, $f(t) = u(t-\frac{\delta t}{2})$; by Equations (38) and (41),

$$B(t) = -\frac{12}{\delta t^3}\left(t - \frac{\delta t}{2}\right)[u(t) - u(t - \delta t)] \qquad (56)$$

so that

$$\overline{B}(s) = \frac{6}{\delta t^2 s}\left[1 + e^{-\delta ts}\right] - \frac{12}{\delta t^3 s^2}\left[1 - e^{-\delta ts}\right] \quad . \qquad (57)$$

By Equation (55),

$$G'(s) = \frac{6}{\delta t^2 s^2}\left[e^{\frac{\delta t}{2}s} + e^{-\frac{\delta t}{2}s}\right] - \frac{12}{\delta t^3 s^3}\left[e^{\frac{\delta t}{2}s} - e^{-\frac{\delta t}{2}s}\right] \quad . \qquad (58)$$

The frequency response of the effective filter applied in obtaining the derivative of the input data is, thus,

$$G'(j\omega) = -\frac{12}{\delta t^2 \omega^2} \cos \frac{\omega\delta t}{2} + \frac{24}{\delta t^3 \omega^3} \sin \frac{\omega \delta t}{2} \qquad (59)$$

Thus, the filtering process used in obtaining $\frac{dF(t)}{dt}$ is somewhat different from that used in obtaining F(t). This difference is a consequence of the neglect of the derivatives of a, b, and c in Equation (25). The magnitude of $G'(j\omega)$ is shown in Figure 5 along with the magnitude of $G(j\omega)$. The fact that $G'(j\omega)$ is, on the average, smaller than $G(j\omega)$ at high frequencies is helpful in obtaining a smooth derivative because the differentiation amplifies the high frequency components of the noise. On the other hand, the selection of a δt to minimize the distortion of the desired signal does not ensure that the distortion of the derivative of the signal will also be minimized. Thus, in the selection of the δt to be used in smoothing a particular set of data, attention must be directed to both the input signal and its derivative and the filtering processes applied to each.

2.34 Multiple Smoothing. Multiple smoothing consists in recycling the output, C(t), in the SMOOTH program through the program any desired number of times. It is equivalent to the common procedure of placing several filters in series in order to obtain the desired attenuation of unwanted frequency components. Since

$$\overline{C}(s) = \overline{f}(s)\ G(s)$$

the output of the SMOOTH program resulting from one recycle, call it $C_1(t)$, will be

$$C_1(t) = L^{-1}\ [\overline{C}(s)\ G(s)] = L^{-1}\ [f(s)\ [G(s)]^2] \quad . \qquad (60)$$

In general, then, the output after n passes (n-1 recycles) will be

$$C_{n-1}(t) = L^{-1}\ [\overline{f}(s)\ [G(s)]^n] \quad .$$

So that the transfer function for n passes is simply

$$G_n(s) = [G(s)]^n \quad . \qquad (61)$$

Because of the sharp roll-off characteristic of $G(j\omega)$ prior to the first zero, it is possible by multiple smoothing to markedly reduce the high frequency lobes without significantly changing the shape of the transfer function below the first zero. To illustrate, on Figure 6 are plotted the transfer functions resulting from one, two, and three passes through the SMOOTH program. Thus, by utilizing three passes, essentially all frequency components above the first zero of $G_3(s)$ will be attenuated by a factor greater than 100.

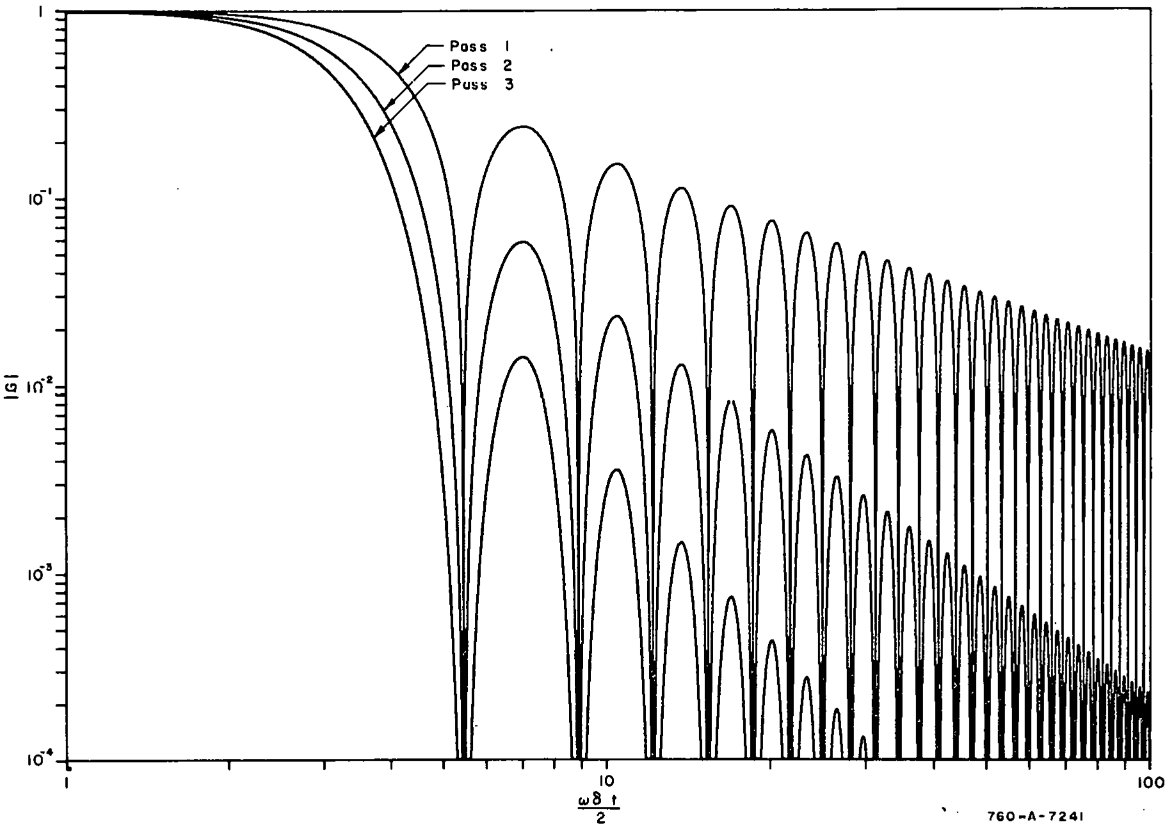

Fig. 6 Transfer functions for one, two, and three passes through SMOOTH.

Because only $C_{n-1}(t)$ is entered as input on the nth pass through SMOOTH,

$$G_n'(s) = G'(s)\ [G(s)]^{n-1} \tag{62}$$

so that the ratio $G_n'(s)/G_n(s)$ is independent of the number of cycles through the SMOOTH program.

3. THE REACTIVITY PROGRAM

3.1 Introduction

The REACTIVITY program was written for the purpose of calculating the reactivity of a reactor from recorded power data. In this calculation, the applicability of the lumped-parameter reactor kinetic equations is assumed. Up to 50 delayed neutron groups may be used. Power data to be used as input to this program must be in natural logarithmic form and must first be processed by the SMOOTH program. Initial conditions are entered by specifying either (a) the initial asymptotic exponential period of the power rise or (b) the initial concentrations of the delayed nèutron precursors. The output of this program consists of the instantaneous values of (a) the reactivity, (b) the compensated reactivity when the initial reactivity perturbation is a step, (c) the linear power, (d) the energy released, and (e) the ratio of the compensated reactivity to the energy released.

3.2 Solution of Equations

In the REACTIVITY program, it is assumed that the time behavior of the reactor can be adequately described by the system of equations

$$\dot{\phi}(t) = \frac{\rho(t) - \bar{\beta}}{\Lambda}\phi(t) + \sum_{i=1}^{n} \lambda_i C_i(t) + s \tag{63}$$

$$\dot{C}_i(t) = \frac{\bar{\beta}_i}{\Lambda}\phi(t) - \lambda_i C_i(t) \tag{64}$$

where

$\phi(t) \equiv$ power of the reactor

$\rho(t) \equiv$ reactivity

$\Lambda \equiv$ prompt neutron generation time

$C_i(t) \equiv$ concentration of i^{th} delayed neutron precursor

$\lambda_i \equiv$ decay constant of the i^{th} delayed neutron precursor group

$\beta_i \equiv$ effective fraction of delayed neutrons produced by i^{th} precursor group

$\bar{\beta} \equiv \Sigma \bar{\beta}_i$

$s \equiv$ source equivalence.

This system of equations can be written in a more convenient form by defining

$$f_i \equiv \bar{\beta}_i / \bar{\beta} \tag{65}$$

and

$$\omega_i(t) \equiv \frac{\Lambda \lambda_i}{\bar{\beta} f_i} C_i(t) \tag{66}$$

and substituting these quantities into Equations (63) and (64). The system of equations then reduces to

$$\dot{\phi}(t) = \frac{\rho(t) - \bar{\beta}}{\Lambda}\phi(t) + \sum_{i=1}^{n} \frac{\bar{\beta} f_i}{\Lambda} \omega_i(t) + s \tag{67}$$

$$\dot{\omega}_i(t) = \lambda_i \phi(t) - \lambda_i \omega_i(t) \quad . \tag{68}$$

From Equation (67)

$$\frac{\rho(t)}{\bar{\beta}} \equiv \$(t) = 1 + \frac{1}{\phi(t)}\left[\frac{\Lambda}{\bar{\beta}}\dot{\phi}(t) - \sum_{i=1}^{n} f_i \omega_i(t)\right] - \frac{\Lambda}{\bar{\beta}}\frac{S}{\phi(t)} \tag{69}$$

Experimental power data to be used in REACTIVITY must first be converted to natural logarithmic form (see Input Format for SMOOTH) and processed by the SMOOTH program. When $\ell n \phi$ is used as input to SMOOTH, a parabola is fitted to a prescribed number of data points (say ϕ_{j-2}, ϕ_{j-1}, ϕ_j, ϕ_{j+1}, ϕ_{j+2}) such that

$$\ell n \; \phi_j^*(t) \simeq A_j t^2 + B_j t + C_j$$

where

$$\phi_j^*(t) = \phi(t + t_j)$$

(ie, $\phi(t)$ is shifted by t_j). Therefore,

$$\ell n \; \phi(t_j) = \ell n \; \phi_j^*(o) = C_j \tag{70}$$

and

$$\left.\frac{\dot{\phi}(t)}{\phi(t)}\right|_{t=t_j} = \frac{d}{dt} \ell n \; \phi_j^*(t) \Big|_{t=o} = B_j \quad . \tag{71}$$

Hence, from Equation (69)

$$\$(t_j) = 1 + \frac{\Lambda}{\beta} B_j - \frac{1}{\phi(t_j)} \sum_{i=1}^{n} f_i \; \omega_i(t_j) - \frac{\Lambda}{\beta} \frac{s}{\phi(t_j)} \quad . \tag{72}$$

The parameters $\Lambda/\overline{\beta}$ and f_i are input data; therefore, to complete the solution, $\phi(t_j)$ and the ω_i's must be calculated. From Equation (70)

$$\phi(t_j) = e^{C_j} \quad . \tag{73}$$

To evaluate ω_i (t), Equation (68) may be solved to give

$$\omega_i(t) = e^{-\lambda_i t} \int \lambda_i \; e^{\lambda_i \tau} \; \phi(\tau) \; d\tau + e^{-\lambda_i t} \cdot K$$

where K is constant. If $\omega_i(t-\delta)$ is known, $\omega_i(t)$ may be calculated by

$$\omega_i(t) = e^{-\lambda_i t} \int_{t-\delta}^{t} \lambda_i \; e^{\lambda_i \tau} \phi(\tau) \, d\tau + \omega_i \; (t-\delta) \, e^{-\lambda_i \delta} \quad . \tag{74}$$

For the purpose of calculating

$$\int_{t-\delta}^{t} e^{\lambda_i \tau} \; \phi(\tau) \; d\tau$$

it is convenient to have coefficients which correspond to linear data rather than to logarithmic data. The relation between the two sets of coefficients is as follows:

If

$$A_j t^2 + B_j t + C_j = \ell n \; \phi^*(t) \tag{75}$$

and

$$a_j t^2 + b_j t + c_j = \phi^*(t) \tag{76}$$

then, at t = 0,

$$c_j = e^{C_j} \tag{77}$$

$$b_j = c_j B_j \tag{78}$$

and

$$a_j = c_j [A_j + \frac{1}{2} B_j^2] \tag{79}$$

Furthermore, since the coefficients a_j, b_j, and c_j correspond to $\phi^*(t)$ at t = 0, it is convenient to make the following transformation:

$$e^{-\lambda_i t} \int_{t-\delta}^{t} \lambda_i e^{\lambda_i \tau} \phi(\tau) d\tau = \int_{t-\delta}^{t} \lambda_i e^{\lambda_i (\tau - t)} \phi(\tau) d\tau$$

$$= \int_{-\delta}^{0} \lambda_i e^{\lambda_i \tau} \phi(\tau + t) d\tau$$

$$= \int_{-\delta}^{0} \lambda_i e^{\lambda_i \tau} \phi^*(\tau) d\tau \tag{80}$$

where $\phi^*(\tau) = \phi(\tau + t)$. Therefore,

$$\omega_i(t) = \omega_i(t-\delta) e^{-\lambda_i \delta} + \int_{-\delta}^{0} \lambda_i e^{\lambda_i \tau} \phi^*(\tau) d\tau \tag{81}$$

Since

$$\phi^*(\tau) = a_j \tau^2 + b_j \tau + c_j$$

the following may be written:

$$\int_{-\delta}^{0} \lambda_i e^{\lambda_i \tau} \phi^*(\tau) d\tau = \int_{-\delta}^{0} \lambda_i e^{\lambda_i \tau} (a_j \tau^2 + b_j \tau + c_j) d\tau$$

$$= \frac{e^{\lambda_i \tau}}{\lambda_i^2} \left[a_j (\lambda_i^2 \tau^2 - 2\lambda_i \tau + 2) + \lambda_i b_j (\lambda_i \tau - 1) + \lambda_i^2 c_j \right] \Bigg|_{-\delta}^{0}$$

$$= \frac{1}{\lambda_i^2} \Big\{ a_j \left[2 - e^{-\lambda_i \delta} (\lambda_i^2 \delta^2 + 2\lambda_i \delta + 2)\right]$$

$$+ b_j \lambda_i \left[e^{-\lambda_i \delta} (\lambda_i \delta + 1) - 1\right] + c_j \lambda_i^2 \left[1 - e^{-\lambda_i \delta}\right]\Big\} \quad . \tag{82}$$

Defining constants K_{1i}, K_{2i}, and K_{3i} as

$$K_{1i} \equiv \frac{1}{\lambda_i^2} \left[2 - e^{-\lambda_i \delta} (\lambda_i^2 \delta^2 + 2\lambda_i \delta + 2)\right] \tag{83}$$

$$K_{2i} \equiv \frac{1}{\lambda_i} \left[e^{-\lambda_i \delta} (\lambda_i \delta + 1) - 1\right] \tag{84}$$

and

$$K_{3i} \equiv (1 - e^{-\lambda_i \delta}) \tag{85}$$

Equation (82) can be written as

$$\int_{-\delta}^{o} \lambda_i e^{\lambda_i \tau} \phi^*(\tau)\, d\tau = [a_j K_{1i} + b_j K_{2i} + c_j K_{3i}] \tag{86}$$

and Equation (81) can be written as

$$\omega_i(t) = \omega_i(t-\delta) e^{-\lambda_i \delta} + a_j K_{1i} + b_j K_{2i} + c_j K_{3i} \quad . \tag{87}$$

The initial values for ω_i [ie, ω_i (t_o)] may be obtained by two methods: (a) the user may furnish these values as input data; or (b) they may be calculated as described below. (See Input Format, Section III-3.25, page 51.) To calculate ω_i (t_o) it is assumed that, for all $t < t_o$.

$$\phi(t) = K_1 e^{\alpha t} \quad . \tag{88}$$

Then

$$C_i(t) = K_2 e^{\alpha t} \tag{89}$$

and

$$\frac{1}{C_i(t)} \dot{C}_i(t) \Big|_{t=t_o} = \alpha \quad . \tag{90}$$

From Equation (64)

$$C_i(t_o) = \frac{\overline{\beta}_i \phi(t_o)}{\Lambda(\lambda_i + \alpha)} \tag{91}$$

and from Equation (66),

$$\omega_i(t_o) = \frac{\lambda_i \; \phi(t_o)}{\lambda_i + \alpha} \tag{92}$$

With initial values for $\omega_i(t_o)$, $\omega_i(t_1)$ may be calculated from Equation (87); having calculated $\omega_i(t_1)$, $\omega_i(t_2)$ may be calculated in the same manner; and so forth.

From Equations (72), (73), (77), and (87), one obtains finally

$$\$(t_j) = 1 + \frac{\Lambda}{\beta} B_j - \frac{1}{c_j} \sum_{i=1}^{n} f_i \left[\omega_i (t_j - \delta) e^{-\lambda_i \delta} + a_j K_{1i} + b_j K_{2i} + c_j K_{3i} \right] - \frac{\Lambda}{\beta} \frac{s}{c_j} \quad . \tag{93}$$

Equation (93) is the expression used in the REACTIVITY program to calculate the reactivity of the reactor from smoothed power data.

The value for $\$(t_o)$ is calculated from the inhour equation,

$$\$(t_o) = \left[\frac{\Lambda}{\beta} + \sum_{i=1}^{n} \frac{f_i}{\lambda_i + \alpha} \right] \alpha \quad . \tag{94}$$

The compensated reactivity of the system is calculated as

$$\$_c(t) = \$(t) - \$(t_o) \quad . \tag{95}$$

It should be noted that both the calculation of $\$(t_o)$, as described by Equation (94), and the calculation of $\$_c(t)$, as defined by Equation (95), are valid only for step transients. The energy released, E(t), is calculated by

$$E(t_j) = E(t_j - \delta) + \int_{-\delta}^{o} \phi^*(t) \, dt$$

$$= E(t_j - \delta) + a_j \frac{\delta^3}{3} - b_j \frac{\delta^2}{2} + c_j \delta \tag{96}$$

where the initial energy, $E(t_o)$, may be entered as input data or may be calculated as (see Input Format Section III-3.25, page 51).

$$E(t_o) = \frac{\phi(t_o)}{\alpha} \quad . \tag{97}$$

(Note: If initial energy is to be calculated, the initial period must not be zero.)

The ratio

$$b(t) = \$_c(t)/E(t) \tag{98}$$

is also calculated.

4. THE FREQUENCY RESPONSE PROGRAM

4.1 Introduction

The behavior of a linear system may be described mathematically by an expression of the form

$$O(s) = I(s)\ G(s) \tag{99}$$

where I(s) is the Laplace transform of the input to the system, and
O(s) is the Laplace transform of the resultant output of the system.

The function G(s) is called the transfer function of the system. If G(s) is known for a particular linear system, then the time response of that system to any Laplace transformable input function can be determined by finding the inverse Laplace transform of the function, O(s). Thus, the function, G(s), mathematically characterized a linear system. An experimental determination of G(s) is therefore often desirable.

As is well known [4], the form of the transfer function can be determined from a knowledge of the frequency response of the system. Hence, the most common method of determining the transfer function is to directly measure the frequency response of the system. That is, the magnitude and phase of the system output relative to a sinusoidal input is determined for various input frequencies. While this method is usually quite accurate, it can be experimentally cumbersome if, for example, the response at very low frequencies is desired or if it is difficult to introduce a sinusoidal input.

Since the transfer function of a linear system is unique, it can easily be shown that the frequency response can be determined from the transient response of the system. Corresponding to Equation (99), the transfer function, G(s), is defined by

$$G(s) = \frac{O(s)}{I(s)} = \frac{\mathcal{L}[o(t)]}{\mathcal{L}[i(t)]} \quad . \tag{100}$$

Hence, G(s) may be determined from the response of a system in the time domain, o(t), to an arbitrary Laplace transformable input function, i(t). While this method tends to be less accurate than that of directly measuring the frequency response (because the experimental data must be processed by numerical techniques), it does allow the frequency response of a linear system to be determined from the results of a single transient experiment.

The FREQUENCY RESPONSE program has been written for the purpose of computing the frequency response from the transient response of a system. This program will numerically evaluate, at designated values of ω_k, the function

$$G(\omega_k) = \frac{\int_0^\infty A(t)\ e^{-i\omega_k t}\ dt}{\int_0^\infty B(t)\ e^{-i\omega_k t}\ dt} \quad . \tag{101}$$

A(t) and B(t) must be described as pointwise functions at evenly spaced time increments; ie,

$$t_j - t_{j-1} = \Delta t = \text{constant} \quad .$$

Furthermore, $A(t)$ and $B(t)$ must be defined in such a manner that, for some time value t_n, $A(t_m)$ and $B(t_m)$ are constant for $m \geq n$. The restrictions placed upon $A(t_j)$ and $B(t_j)$ are discussed in detail in Section II-4.2.

By means of an option, $B(t)$ may be specified to be a unit impulse so that

$$\int_0^\infty A(t)\, e^{-i\omega_k t}\, dt \tag{102}$$

is calculated.

The output of the program is as follows:

(1) Radian Frequencies (ω_k - designated by the user)

(2) The real part of $G(\omega_k)$

(3) The imaginary part of $G(\omega_k)$

(4) $|G(\omega_k)|$

(5) Phase angle of $G(\omega_k)$ in degrees

(6) $20 \log_{10} |G(\omega_k)|$

(7) $\log_{10} \omega_k$.

Careful consideration must be given to the accuracy that may be expected from this program. This is discussed in detail in Section II-4.3.

4.2 Solution of Equations

The purpose of the FREQUENCY RESPONSE program is to calculate the ratio of the unilateral Fourier transforms of digitized experimental data of the form

$$[t_j,\ f(t_j)];\quad j = 0, 1, 2, 3, \ldots, n \quad .$$

As was pointed out in the introduction, the transfer function is defined by the ratio of the Laplace transforms of the output and input, ie,

$$G(s) = \frac{L[o(t)]}{L[i(t)]} \quad .$$

However, for the purpose of a frequency response analysis, it is sufficient to consider the unilateral Fourier transforms; ie, s is replaced with $i\omega$.

The Laplace transform of f(t) exists if f(t) satisfies the following restrictions:

(1) The function f(t) must be piecewise regular.

(2) There exists an α such that, for the real part of $s > \alpha$,

$$\int_0^\infty f(t)\, e^{-st}\, dt \text{ converges} \quad .$$

(3) For numerical evaluation of this integral, it is sufficient that f(t) satisfy the further restriction that there exists t_n such that for all $t_m \geq t_n$,

$$f(t_m) = f(t_n) \quad .$$

Any function which describes a physical phenomenon satisfies restrictions 1 and 2. Consequently, in determining the applicability of this program only condition 3 must be of concern.

If f(t) satisfies conditions 1, 2, and 3, the unilateral Fourier transform may be numerically evaluated as follows:

$$\int_0^\infty f(t)\, e^{-i\omega t}\, dt = \int_0^\infty [f(t) - f(t_n)]\, e^{-i\omega t} + \int_0^\infty f(t_n)\, e^{-i\omega t}\, dt \quad . \tag{103}$$

Since it is assumed that $f(t) = f(t_n)$, a constant, for $t \geq t_n$,

$$\int_0^\infty f(t)\, e^{-i\omega t}\, dt = \int_0^{t_n} [f(t) - f(t_n)]\, e^{-i\omega t}\, dt + \int_0^\infty f(t_n)\, e^{-i\omega t}\, dt \tag{104}$$

Now

$$\int_0^\infty f(t_n)\, e^{-st}\, dt = \frac{f(t_n)}{s}$$

and

$$\lim_{s \to i\omega} \int_0^\infty f(t_n)\, e^{-st}\, dt = \frac{f(t_n)}{i\omega} \quad . \tag{105}$$

Hence, to complete the evaluation of $\int_0^\infty f(t)\, e^{-i\omega t}\, dt$, it remains to evaluate

$$\int_0^{t_n} [f(t) - f(t_n)]\, e^{-i\omega t}\, dt = \int_0^{t_n} f(t)\, e^{-i\omega t}\, dt + \frac{f(t_n)}{i\omega} \left(e^{-i\omega t_n} - 1 \right) \quad . \tag{106}$$

Consider the integral

$$\int_0^{t_n} f(t)\, e^{-i\omega t}\, dt = \int_0^{t_n} f(t)\, [\cos \omega t - i \sin \omega t]\, dt \quad . \tag{107}$$

In order to evaluate Equation (107), the function f(t) is approximated by a series of straight lines, so that in the interval $t_{j-1} \leq t \leq t_j$,

$$f(t) = f_{j-1} + \frac{f_j - f_{j-1}}{t_j - t_{j-1}} [t - t_{j-1}] \quad . \tag{108}$$

It is assumed for convenience that $t_j - t_{j-1}$ is constant, so that

$$f(t) = f_{j-1} + \frac{f_j - f_{j-1}}{\Delta t} (t - t_{j-1}) \quad . \tag{109}$$

Then, considering the first term on the right-hand side of Equation (107) and letting $t_o = 0$,

$$\int_o^{t_n} f(t) \cos \omega t \, dt$$

$$= \sum_{j=1}^{n} \int_{t_{j-1}}^{t_j} [f_{j-1} + \frac{f_j - f_{j-1}}{\Delta t} (t - t_{j-1})] \cos \omega t \, dt \tag{110}$$

which reduces to

$$\int_o^{t_n} f(t) \cos \omega t \, dt$$

$$= \frac{f_n}{\omega} \sin \omega t_n - \frac{2}{\omega^2 \Delta t} \sin \frac{\omega \Delta t}{2} \sum_{j=1}^{n} (f_j - f_{j-1}) \sin \omega (t_{j-1} + \frac{\Delta t}{2}) \; . \tag{111}$$

In a similar manner,

$$\int_o^{t_n} f(t) \sin \omega t \, dt = \sum_{j=1}^{n} \int_{t_{j-1}}^{t_j} \left[f_{j-1} + \frac{f_j - f_{j-1}}{\Delta t} (t - t_{j-1})\right] \sin \omega t \, dt$$

$$= \frac{f_o}{\omega} - \frac{f_n}{\omega} \cos \omega t_n + \frac{2}{\omega^2 \Delta t} \sin \frac{\omega \Delta t}{2} \sum_{j=1}^{n} (f_j - f_{j-1}) \cos \omega (t_{j-1} + \frac{\Delta t}{2}) \; . \tag{112}$$

Then for

$$G(\omega) = \frac{L[A(t)]}{L[B(t)]}$$

and two pointwise functions, $A(t_j)$ and $B(t_j)$, we define

R'_{N_k} = real part of the numerator of $G(\omega)$

I'_{N_k} = imaginary part of the numerator of $G(\omega)$

R'_{D_k} = real part of the denominator of $G(\omega)$

I'_{D_k} = imaginary part of the denominator of $G(\omega)$.

Then, by noting that

$$\frac{f(t_n)}{i\omega}\left(e^{-i\omega t_n} - 1\right) = \frac{f(t_n)}{\omega}\left[-\sin \omega t_n + i\,(1 - \cos \omega t_n)\right] \tag{113}$$

and by employing Equations (104), (105), (106), (111), and (112),

$$R'_{N_k} = \frac{2}{\omega_k^2 \Delta t} \sin \frac{\omega_k \Delta t}{2} \sum_{j=1}^{n} (A_j - A_{j-1}) \sin \omega_k \left(t_{j-1} + \frac{\Delta t}{2}\right) \tag{114}$$

$$I'_{N_k} = \left\{ -\frac{A_o}{\omega_k} + \frac{2}{\omega_k^2 \Delta t} \sin \frac{\omega_k \Delta t}{2} \sum_{j=1}^{n} (A_j - A_{j-1}) \cos \omega_k \left(t_{j-1} + \frac{\Delta t}{2}\right) \right\} \tag{115}$$

$$R'_{D_k} = \frac{2}{\omega_k^2 \Delta t} \sin \frac{\omega_k \Delta t}{2} \sum_{j=1}^{n} (B_j - B_{j-1}) \sin \omega_k \left(t_{j-1} + \frac{\Delta t}{2}\right) \tag{116}$$

and

$$I'_{D_k} = \left\{ -\frac{B_o}{\omega_k} + \frac{2}{\omega_k^2 \Delta t} \sin \frac{\omega_k \Delta t}{2} \sum_{j=1}^{n} (B_j - B_{j-1}) \cos \omega_k \left(t_{j-1} + \frac{\Delta t}{2}\right) \right\}. \tag{117}$$

Multiplying the numerator and denominator of $G(\omega)$ [ie, Equations (114), (115), (116), and (117)] by

$$-\frac{\omega_k^2 \Delta t}{2 \sin \frac{\omega_k \Delta t}{2}}$$

$G(\omega_k)$ may be written with the real and imaginary parts of the numerator and denominator as follows:

$$R_{N_k} = \sum_{j=1}^{n} (A_j - A_{j-1}) \sin \omega_k \left(t_{j-1} + \frac{\Delta t}{2}\right) \tag{118}$$

$$I_{N_k} = \frac{A_o\, \omega_k \Delta t}{2 \sin \frac{\omega_k \Delta t}{2}} + \sum_{j=1}^{n} (A_j - A_{j-1}) \cos \omega_k \left(t_{j-1} + \frac{\Delta t}{2}\right) \tag{119}$$

$$R_{D_k} = \sum_{j=1}^{n} (B_j - B_{j-1}) \sin \omega_k \left(t_{j-1} + \frac{\Delta t}{2}\right) \tag{120}$$

and

$$I_{D_k} = \frac{B_o \omega_k \Delta t}{2 \sin \frac{\omega_k \Delta t}{2}} + \sum_{j=1}^{n} (B_j - B_{j-1}) \cos \omega_k \left(t_{j-1} + \frac{\Delta t}{2}\right) . \tag{121}$$

The function $G(\omega_k)$ may now be computed from

$$G(\omega_k) = \frac{R_{N_k} + i\, I_{N_k}}{R_{D_k} + i\, I_{N_k}} \tag{122}$$

For cases in which the unilateral Fourier integral of a single function, A(t), rather than the ratio of two integrals is desired, an option is provided so that

$$R_{D_k} = - \frac{\omega_k^2 \Delta t}{2 \sin \frac{\omega_k \Delta t}{2}} \tag{123}$$

and $I_{D_k} = 0$. (See FREQUENCY RESPONSE Control Card: ratio control, page 54.) Note that this option is equivalent to an input in which B(t) is the unit impulse function (or delta function).

4.3 Error Analysis and Criteria

Due to the nature of the assumptions and approximations made in the development of the FREQUENCY RESPONSE program, the output is subject to error; and some care must be exercised in the use of the program if meaningful results are to be obtained. This section is devoted to (a) a discussion of the various errors which may occur, (b) the development of criteria for determining bounds on the errors, and (c) the development of means whereby the errors may be minimized. The errors which may occur in the output of FREQUENCY RESPONSE can be divided into three categories.

(1) Errors due to round-off in the computer

(2) Errors due to truncation of the function, f(t), with the assumption that $f(t) = f(t_n)$ for $t \geq t_n$

(3) Errors arising from the representation of f(t) in the interval $0 \leq t \leq t_n$ by a sequence of straight lines.

Each type error is treated separately below.

4.31 Round-off Error. In this program, certain integrals are evaluated by numerical processes; and the possibility, therefore, exists that the error due to round off of numerical quantities may accumulate and become significant. To test the program for errors of this type, use has been made of the following theorem: (Proofs of all theorems are given in Appendix A.)

THEOREM I: If $f(t) = f(t_n - t)$ in the interval $0 \leq t \leq t_n$ and zero elsewhere and if

$$F(\omega) = \int_0^\infty f(t)\, e^{-i\omega t}\, dt \tag{124}$$

then for

$$\omega = (2m - 1)\pi/t_n$$

(m an integer) the real part of F(t) is zero and for

$$\omega = 2m\pi/t_n$$

the imaginary part of F(t) is zero.

From Theorem I it follows that if the hypothesis of the theorem is satisfied so that the real or imaginary part of the unilateral Fourier transform is zero, then the value of the real or imaginary part of the transform as computed by FREQUENCY RESPONSE is the absolute round-off error. Two test problems have been run in order to evaluate the round-off error. In each test, data points were arranged to satisfy the hypothesis of Theorem I. In Test Problem 1, frequencies were selected such that $\omega = (2m - 1)\pi/t_n$. As shown on page 30, the real part obtained is essentially zero. Similarly, in Test Problem 2, frequencies were selected such that $\omega = 2m\pi/t_n$; and the imaginary part obtained is essentially zero, as shown on page 31. These results indicate that error due to round-off is negligible in this program.

4.32 Truncation Error. In order to obtain an exact evaluation of the unilateral Fourier transform of a function, f(t), the function must be known for all $t \geq 0$. In practical problems the function f(t) is never known for all time, and some approximation is required. In the FREQUENCY RESPONSE program it has been assumed that for $t \geq t_n$, $f(t) = f(t_n)$, ie, the function is truncated at t_n and assumed constant thereafter. Hence, if $f(t_n)$ is not in fact equal to f(t) when $t > t_n$, some error must be expected in the results given by FREQUENCY RESPONSE. The nature of the error resulting from truncation is given by the following theorem and its corollaries: (Proofs are given in Appendix A.)

THEOREM II:

Let
$$F(\omega) = \int_0^\infty f(t)\, e^{-i\omega t}\, dt \ .$$

$$f^*(t) = f(t) \text{ for } 0 \leq t \leq t_n$$

$$f^*(t) = f(t_n) \text{ for } t > t_n$$

then

$$F(\omega) - F^*(\omega) = \int_{t_n}^\infty [f(t) - f(t_n)]\, e^{-i\omega t}\, dt \ . \tag{125}$$

Corollary 1: $$|F(\omega) - F^*(\omega)| \leq \int_{t_n}^\infty |f(t) - f(t_n)|\, dt \ . \tag{126}$$

SPORT 04/07/65 TEST PROBLEM ONE FOR FREQUENCY RESPONSE

RECORD NO 444449003 CHANNEL 3 NUMERATOR WAS WORD 1

FREQUENCIES IN CPS

FREQUENCY	LOG W	REAL G(IW)	IMAG. G(IW)	MAG. G	PHASE ANGLE	20 LOG(MAG. G)
0.5000	-0.301	8.6456467E-05	-5.1602150E 01	5.1602149E 01	-89.99990463	34.2533560
1.5000	0.176	3.8600274E-05	-1.9111872E 00	1.9111872E 00	-89.99884415	5.6260645
2.5000	0.398	1.8169063E-05	-4.1281453E-01	4.1281453E-01	-89.99747849	-7.6849006
5.5000	0.740	3.7220438E-06	-3.8767978E-02	3.8767978E-02	-89.99450302	-28.2305374
7.5000	0.875	1.9717948E-06	-1.5288522E-02	1.5288522E-02	-89.99261475	-36.3126903
9.5000	0.978	1.1921578E-06	-7.5225215E-03	7.5225215E-03	-89.99092484	-42.4727311
14.5000	1.161	5.3867123E-07	-2.1153061E-03	2.1153061E-03	-89.98541260	-53.4925356
19.5000	1.290	1.7688884E-07	-8.6949405E-04	8.6949406E-04	-89.98834610	-61.2146688
24.5000	1.389	1.7638720E-07	-4.3832581E-04	4.3832584E-04	-89.97694397	-67.1640587
29.5000	1.470	1.2222332E-07	-2.5099536E-04	2.5099538E-04	-89.97210312	-72.0066853
39.5000	1.597	6.8442393E-08	-1.0448620E-04	1.0448622E-04	-89.96247101	-79.6188202
49.5000	1.695	3.2656957E-08	-5.3022265E-05	5.3022275E-05	-89.96471405	-85.5108328
59.5000	1.775	2.9752275E-08	-3.0507418E-05	3.0507432E-05	-89.94412613	-90.3118868
69.5000	1.842	1.2397946E-08	-1.9090617E-05	1.9090621E-05	-89.96279144	-94.3835993
79.5000	1.900	1.8401851E-08	-1.2735394E-05	1.2735407E-05	-89.91721344	-97.8997440
99.5000	1.998	1.6762870E-08	-6.4757601E-06	6.4757817E-06	-89.85168838	-103.7741575

CALCULATIONS REQUIRED 1 MIN 34.8 SEC

TOTAL PROBLEM TIME WAS 3 MIN 6.8 SEC

SPORT 04/07/65 TEST PROBLEM TWO FOR FREQUENCY RESPONSE

RECORD NO 444449003 CHANNEL 3 NUMERATOR WAS WORD 1

FREQUENCIES IN CPS

FREQUENCY	LOG W	REAL G(IW)	IMAG. G(IW)	MAG. G	PHASE ANGLE	20 LOG(MAG. G)
1.0000	-0.000	-2.0264149E 01	6.4875532E-05	2.0264149E 01	-180.00018120	26.1345675
2.0000	0.301	-5.0660414E 00	6.7583003E-06	5.0660414E 00	-180.00007439	14.0933748
3.0000	0.477	-2.2515695E 00	2.1101175E-06	2.2515695E 00	-180.00005150	7.0497073
6.0000	0.778	-5.6289249E-01	4.9901540E-09	5.6289249E-01	-179.99999809	-4.9914908
8.0000	0.903	-3.1662709E-01	-1.5826264E-07	3.1662709E-01	-179.99996948	-9.9890387
10.0000	1.000	-2.0264128E-01	-1.0645052E-07	2.0264128E-01	-179.99996758	-13.8654418
15.0000	1.176	-9.0062792E-02	-1.3396287E-07	9.0062791E-02	-179.99991417	-20.9090919
20.0000	1.301	-5.0660339E-02	-7.9316752E-08	5.0660338E-02	-179.99990845	-25.9066386
25.0000	1.398	-3.2422619E-02	-9.9581325E-08	3.2422618E-02	-179.99982071	-29.7830386
30.0000	1.477	-2.2515687E-02	-7.6169123E-08	2.2515687E-02	-179.99980354	-32.9502964
40.0000	1.602	-1.2665081E-02	-4.7837641E-08	1.2665081E-02	-179.99978256	-37.9478407
50.0000	1.699	-8.1056552E-03	-5.7173657E-08	8.1056551E-03	-179.99959373	-41.8242373
60.0000	1.778	-5.6289322E-03	-4.7825430E-08	5.6289321E-03	-179.99950981	-44.9914799
70.0000	1.845	-4.1355295E-03	-2.4348635E-08	4.1355295E-03	-179.99966049	-47.6693778
80.0000	1.903	-3.1662633E-03	-2.6159365E-08	3.1662633E-03	-179.99952316	-49.9890599
100.0000	2.000	-2.0264188E-03	-2.3338057E-08	2.0264187E-03	-179.99933815	-53.8654165

CALCULATIONS REQUIRED 1 MIN 34.8 SEC

TOTAL PROBLEM TIME WAS 2 MIN 18.1 SEC

Corollary 2: If $\phi(\omega)$ and $\phi^*(\omega)$ are the phase angles of $F(\omega)$ and $F^*(\omega)$, respectively, then

$$|\sin(\phi - \phi^*)| \leq \frac{\int_{t_n}^{\infty} |f(t) - f(t_n)| \, dt}{|F^*(\omega)|} \quad . \tag{127}$$

Corollaries 1 and 2 give, respectively, the limits on the gain and phase error due to truncation. It is apparent that these errors may be minimized by selecting $f(t_n)$ such that

$$\int_{t_n}^{\infty} |f(t) - f(t_n)| \, dt$$

is minimized. Hence, in order to ensure that the truncation error is small or to determine the limits on the error resulting from truncation, some knowledge of the behavior of f(t) for $t > t_n$ is necessary. For most practical cases the behavior of f(t) for $t > t_n$ can be approximated, and the errors due to truncation can be estimated by Corollaries 1 and 2.

In a number of practical cases, the function, f(t), ultimately decays in an exponential manner to a final value. For this rather common case, the errors due to truncation are given by the following corollary to Theorem II.

Corollary 3: If, for $t \geq t_n$,

$$f(t) = \frac{f(t_n) - f(\infty)}{m} \sum_{k=1}^{m} e^{-\alpha_k (t - t_n)} + f(\infty) \tag{128}$$

and

$$f^*(t) = f(t_n)$$

then

$$|F(\omega) - F^*(\omega)| = \frac{|f(t_n) - f(\infty)|}{m} \left[\left(\sum \frac{\alpha_K}{\alpha_K^2 + \omega^2} \right)^2 + \left(\frac{m}{\omega} - \sum \frac{\omega}{\alpha_K^2 + \omega^2} \right)^2 \right]^{1/2} \tag{129}$$

If coefficients, α_K, can be found which adequately describe the real function, f(t), and a reasonable estimate for $f(\infty)$ is available, this corollary can be applied directly to data. This, however, is generally not the case; for if these parameters were known, a better estimate of f*(t) would have been made originally. The usefulness of this corollary, then, lies in the fact that for extreme values of ω ($\omega \to 0$ and $\omega \to \infty$) the ratio $|F - F^*|/F^*$ (and consequently $|\sin(\phi - \phi^*)|$) varies inversely as $\omega |F^*|$.

For the case where $|F^*|$ approaches a constant as $\omega \to 0$ (as is the case for a linear system), the error due to truncation will become large for small values of ω . If answers at small frequencies are desired, the number $f(t_n) - f(\infty)$ must be small. On the other hand, it follows from this corollary that if $|F^*|$ decreases as $1/\omega$ (for $\omega \to \infty$, $|F^*|$ decreases at 20 dB per decade), then the error due to truncation is constant. At higher rates of decreases for $|F^*|$, the truncation error becomes insignificant. For analyzing power transients such as those recorded from the Spert reactors, one can conclude that truncation error may be of concern for small values of ω, but of no concern otherwise.

To illustrate the nature of the truncation error, the Fourier transforms of the following two functions were computed by means of FREQUENCY RESPONSE.

$$f_1(t) = \begin{cases} e^{-t} , & 0 \leq t \leq 10 \\ 0 , & t > 10 \end{cases} \tag{130}$$

$$f_2(t) = \begin{cases} e^{-t} , & 0 \leq t \leq 5 \\ e^{-5} = 0.00673 , & t > 5 \end{cases} . \tag{131}$$

It can easily be shown that the transform of $f_1(t)$ as computed by FREQUENCY RESPONSE is essentially free of truncation error, ie,

$$\int_0^{\infty} f_1(t)\, e^{-i\omega t}\, dt \approx \frac{1}{1 + j\omega} . \tag{132}$$

For $f_2(t)$, however, Corollary 3 indicated that at $\omega = 10^{-1}$,

$$F_1(\omega) - F_2(\omega) = 0.067 = 0.56 \text{ db} \tag{133}$$

and

$$|\psi_1 - \phi_2| \leq 3.9^{\circ} . \tag{134}$$

At $\omega = 10^{-2}$,

$$|F_1(\omega) - F_2(\omega)| = 0.67 = 4.4 \text{ db} \tag{135}$$

and

$$|\phi_1(\omega) - \phi_2(\omega)| \leq 42^{\circ} . \tag{136}$$

Thus, the phase error due to truncation should be evident for $\omega \geq 10^{-1}$, and the magnitude error should be evident for $\omega \geq 10^{-2}$. This is illustrated in Figures 7 and 8.

In summary, the principal effect of truncation of the function, f(t), is to produce a low frequency error in the unilateral Fourier transform. This error can be minimized by minimizing

$$\int_0^{\infty} |f(t_n) - f(\infty)|\, dt .$$

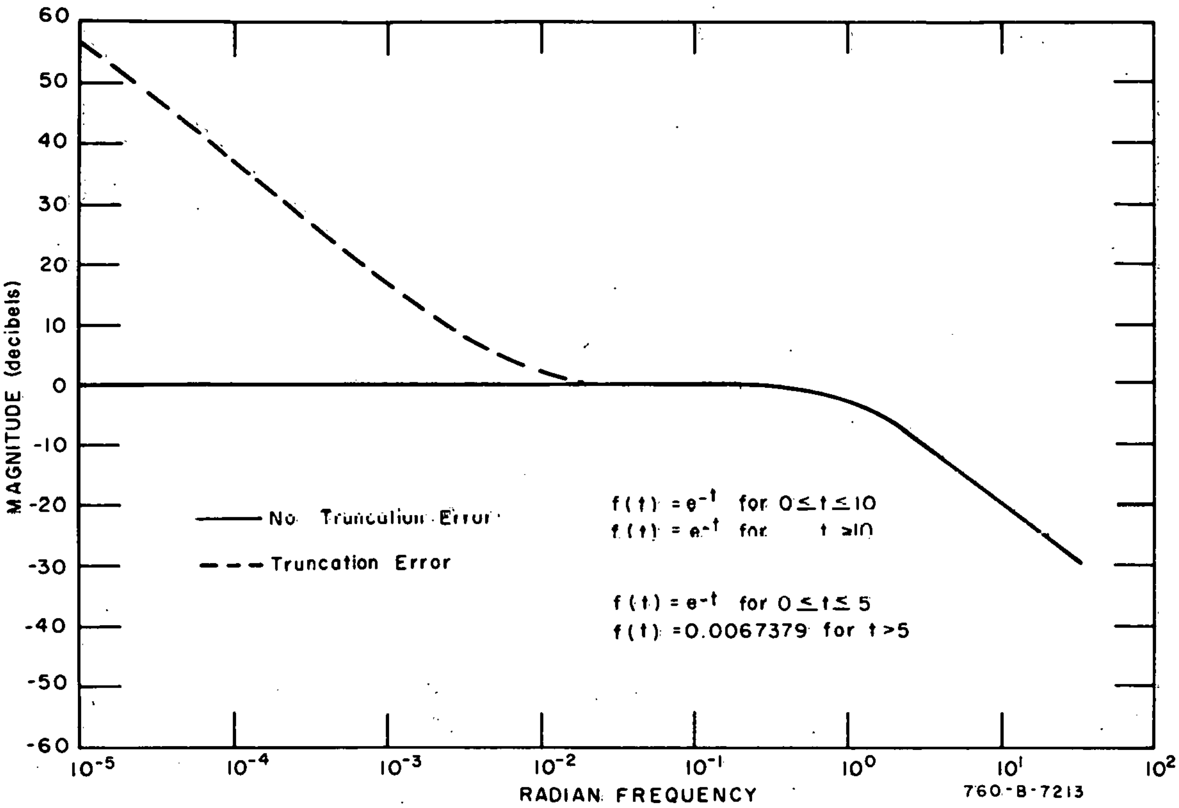

Fig. 7 Magnitude of transform as computed by FREQUENCY RESPONSE to demonstrate round-off error.

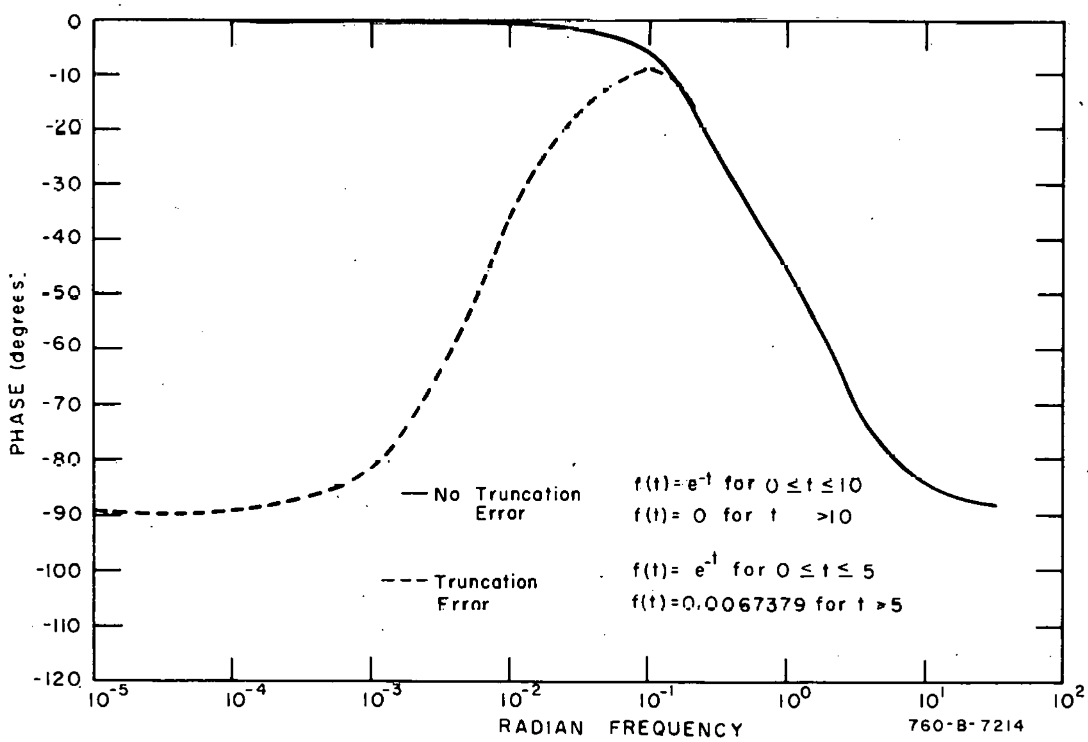

Fig. 8 Phase of transform as computed by FREQUENCY RESPONSE to demonstrate round-off error.

If care is used in selecting $f(t_n)$, the truncation error can usually be made negligible in the frequency range of interest.

4.33 Error Resulting from Straight Line Approximation to the Input Functions. In the input to FREQUENCY RESPONSE, each function for which the unilateral Fourier transform is desired is represented by a set of points of the form, $[t_j, f(t_j)]$. For convenience in evaluating the integrals, it is assumed in the program that the variation of the input function between successive points is linear; ie, the set of points is connected by a sequence of straight lines. The Fourier transform computed, therefore, is that of a sequence of straight lines and is exact to within the numerical accuracy of the computer. Since the straight line frequency is usually not the desired function but an approximation of the function, some error is present in the resultant transform. In general, if $f(t)$ is the desired function and $f^*(t)$ is an approximation of $f(t)$, the bounds of the errors in the magnitude and phase of the resultant Fourier transform are given respectively by Theorems III and IV. (Proofs appear in Appendix A.)

THEOREM III:

Let

$$F(\omega) = \int_0^{t_n} f(t)\, e^{-i\omega t}\, dt \tag{137}$$

and suppose

$$|f(t) - f^*(t)| \leq \epsilon \quad \text{for} \quad 0 \leq t \leq t_n \ . \tag{138}$$

If

$$\frac{\epsilon\, t_n}{|F^*(\omega)|} \leq k \tag{139}$$

then

$$\frac{|F(\omega) - F^*(\omega)|}{|F^*(\omega)|} \leq k \ . \tag{140}$$

THEOREM IV:

Let

$$F(\omega) = \int_0^{t_n} f(t)\, e^{-i\omega t}\, dt$$

and let ϕ be the phase of $F(\omega)$. Suppose

$$|f(t) - f^*(t)| \leq \epsilon \quad \text{for} \quad 0 \leq t \leq t_n \ .$$

If

$$\frac{\epsilon\, t_n}{|F^*(\omega)|} \leq k \tag{141}$$

then

$$|\sin(\phi - \phi^*)| \leq k \ . \tag{142}$$

In addition of Theorems III and IV, one may also apply the following theorem and its corollaries to determine the bounds of the error.

THEOREM V:

Let:

$$F(\omega) = \int_0^{t_n} f(t)\, e^{-\omega t}\, dt \quad .$$

Suppose that

$$f(0) = f^*(0) \text{ and } f(t_n) = f^*(t_n)$$

and that on $(0, t_n)$, the i^{th} derivatives of f(t) and f*(t) are continuous for all $i < m$ and that the m^{th} derivative is sectionally continuous. If

$$\left| \frac{d^m}{dt^m} [f(t) - f^*(t)] \right| \leq \epsilon_m \text{ on } (0, t_n) \tag{143}$$

then

$$\frac{\big||F(\omega)| - |F^*(\omega)|\big|}{|F^*(\omega)|} \leq \sum_{j=1}^{m-1} \frac{1}{\omega^{j+1}\, |F^*(\omega)|} \left| \frac{d^j}{dt^j} [f(t) - f^*(t)] \right|_0^{t_n}$$

$$+ \frac{\epsilon_m t_n}{\omega^m |F^*(\omega)|} \tag{144}$$

$$|\sin (\phi - \phi^*)| \leq \sum_{j=1}^{m-1} \frac{1}{\omega^{j+1}\, |F^*(\omega)|} \left| \frac{d^j}{dt^j} f(t) - f^*(t) \right|_0^{t_n}$$

$$+ \frac{\epsilon_m t_n}{\omega^m |F^*(\omega)|} \tag{145}$$

Because of the difficulty in determining ϵ_n, application of Theorem V is generally practical only for m =1. For this case, Theorem V can be written in a simplified form.

Let

$$F(\omega) = \int_0^{t_n} f(t)\, e^{-\omega t}\, dt$$

and suppose that f(o) = f*(o) and $f(t_n) = f^*(t_n)$.

If

$$\left| \frac{d}{dt} [f(t) - f^*(t)] \right| \leq \epsilon$$

then

$$\frac{|F(\omega) - F^*(\omega)|}{|F^*(\omega)|} \leq \frac{\epsilon\ t_n}{\omega\,|F^*(\omega)|} \qquad (146)$$

and

$$|\sin(\phi - \phi^*)| \leq \frac{\epsilon\ t_n}{\omega\,|F^*(\omega)|} \qquad (147)$$

In certain cases, the bounds on the errors as given by the corollaries to Theorem V may be smaller in some frequency ranges than the bounds given by Theorems III and IV. Therefore, both of the above methods should be applied wherever possible in order to minimize the estimated error. The following examples demonstrate the use of the above theorems and corollaries to determine the envelope within which the transform, F, must lie.

To demonstrate the effect of various time steps and, consequently, various errors in the straight line approximations, four test problems are given below. The function

$$f(t) = e^{-2t} - e^{-4t} \quad \text{for } 0 \leq t \leq 10$$

$$f(t) = 0 \quad \text{for } t > 10 \qquad (148)$$

was approximated by the method described in Section II-4.2 using time steps of 0.5, 0.25, 0.1, and 0.025. Plots of the magnitude of the results are given in Figures 9 through 12.

To apply Theorem III, the maximum difference between f(t) and f*(t) must be known. For a time step of 0.1, the maximum error in this case can be determined to be 0.1; ie,

$$|f - f^*| < 0.1 \quad . \qquad (149)$$

Therefore, since

$$\big||F| - |F^*|\big| \leq |F - F^*| \qquad (150)$$

from Theorem III,

$$\frac{\big||F| - |F^*|\big|}{|F^*|} \leq \frac{0.1}{|F^*|} \qquad (151)$$

or

$$20 \log \left(1 - \frac{0.1}{|F^*|}\right) \leq 20 \log \frac{|F|}{|F^*|} \leq 20 \log \left(1 + \frac{0.1}{|F^*|}\right) \quad . \qquad (152)$$

A plot of the envelope is given in Figure 11.

To apply Theorem V, the maximum difference between the derivatives of f(t) and f*(t) must be known. For a time step of 0.1, this maximum difference can be determined to be 0.27. Therefore, from Theorem V,

$$\frac{\big||F| - |F^*|\big|}{|F^*|} \leq \frac{2.7}{\omega\,|F^*|} \quad . \qquad (153)$$

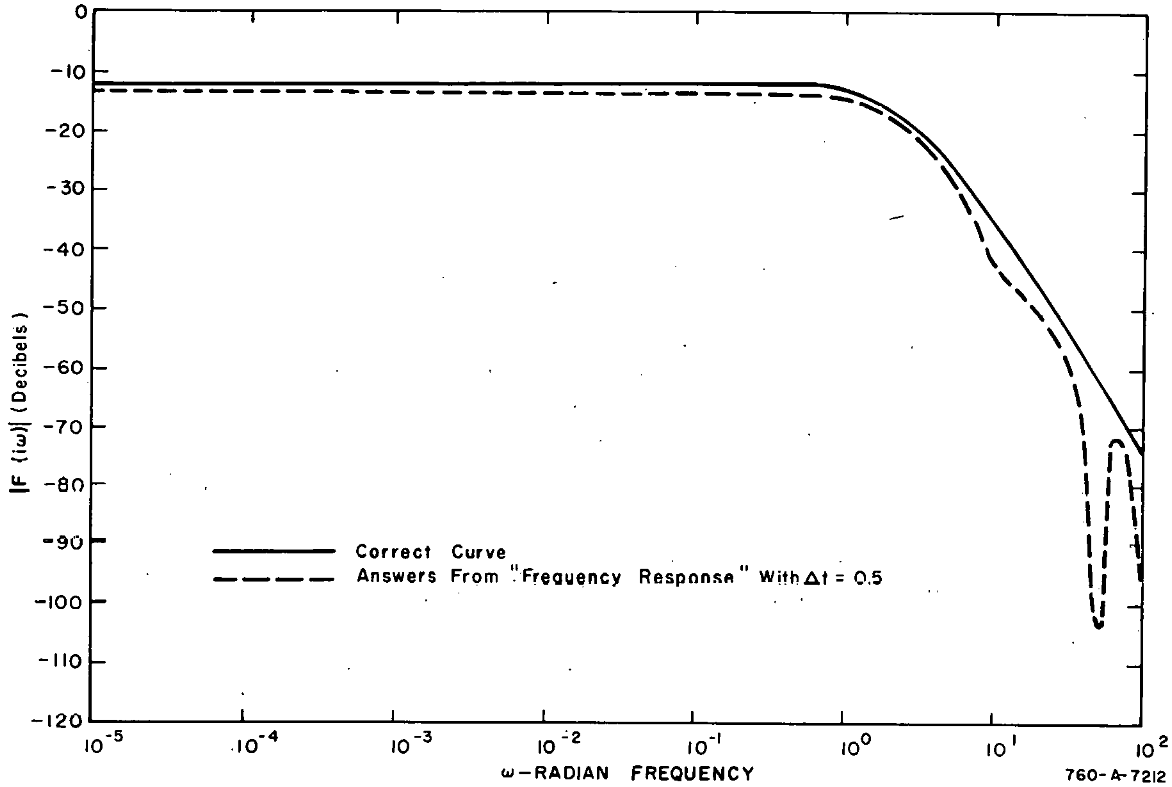

Fig. 9 Magnitude of transform as computed by FREQUENCY RESPONSE to demonstrate effect of Δt ($\Delta t = 0.5$).

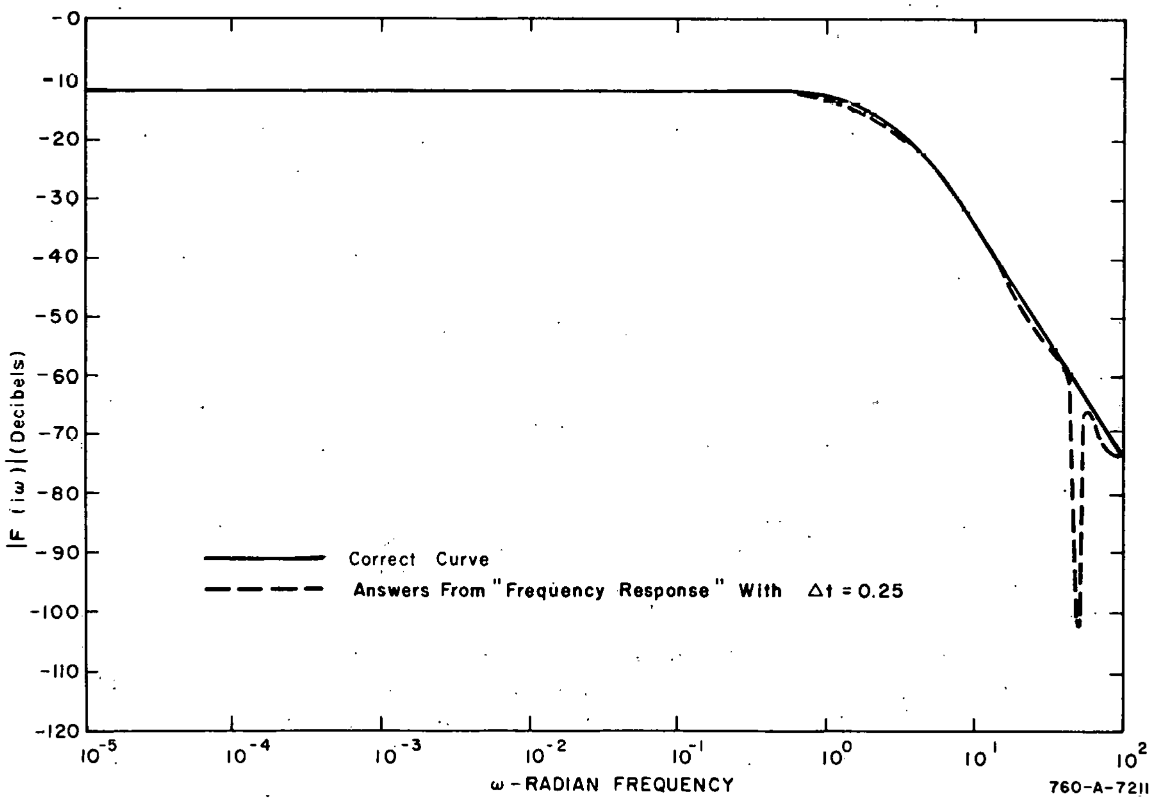

Fig. 10 Magnitude of transform as computed by FREQUENCY RESPONSE to demonstrate effect of Δt ($\Delta t = 0.25$).

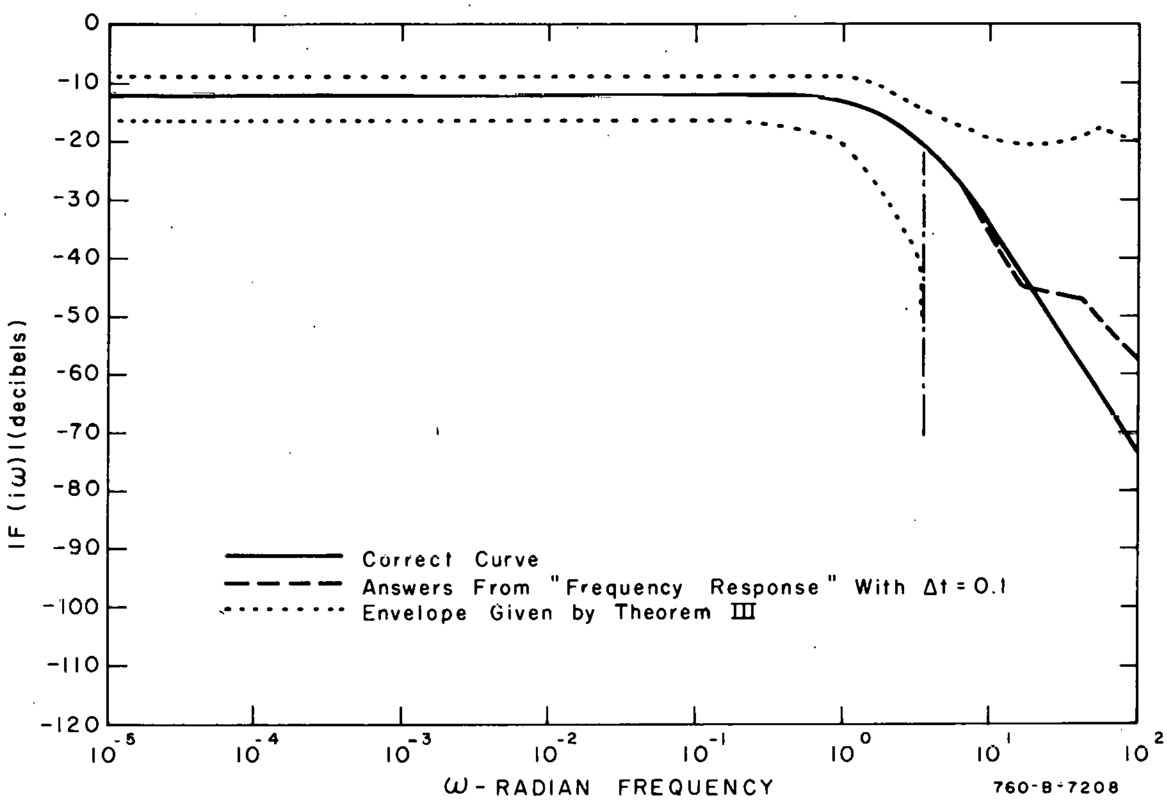

Fig. 11 Magnitude of transform as computed by FREQUENCY RESPONSE and error envelope to demonstrate effect of Δt ($\Delta t = 0.1$).

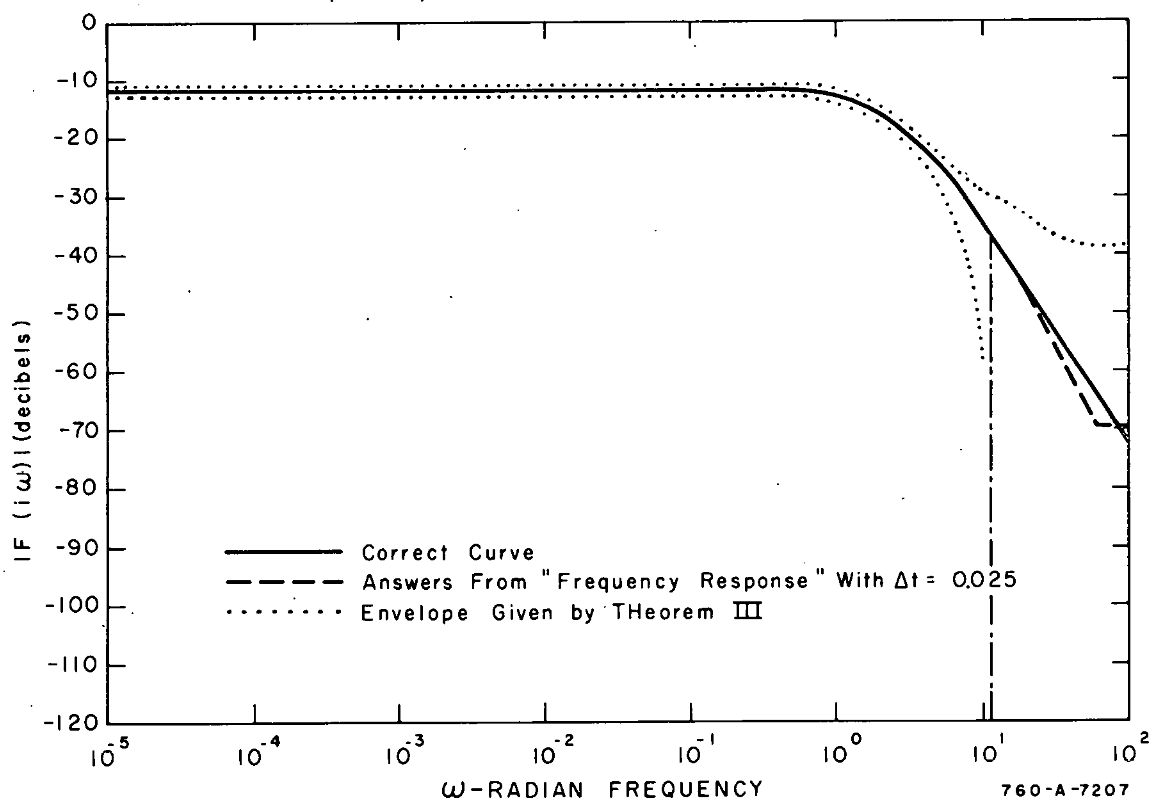

Fig. 12 Magnitude of transform as computed by FREQUENCY RESPONSE and error envelope to demonstrate effect of Δt ($\Delta t = 0.025$).

For this particular test problem, the upper limit of the error as given by Theorem III is smaller for values of $\omega < 27$ than that given by Theorem V. Practically, nothing is gained by using Theorem V, and the envelope shown in Figure 11 was calculated using Theorem III exclusively. The envelope calculated for the case of $t = 0.025$ is shown in Figure 12 and is, as would be expected, somewhat smaller than that obtained for $t = 0.1$. As indicated by the example, for a reasonably well-behaved function, the error criteria are overly restrictive. This is to be expected from the general nature of the theorems.

To summarize, the errors in the output of FREQUENCY RESPONSE due to straight line approximation are unavoidable in this program. However, the actual transform lies within the envelope determined by Theorems III, IV, and V and their corollaries; and the size of the envelope can be reduced by reducing the time increment (and consequently $|f - f^*|$) of the input data.

4.34 <u>Error in the Ratio of Two Functions.</u> The discussion above has been restricted to the transform of a single function; ie, the case

$$f(\omega) \doteq \int_0^\infty f(t)\, e^{-i\omega t}\, dt \quad .$$

However, the error analysis may be extended to the ratio of two transforms by applying the criteria developed. Following the notation scheme used in the above discussion, let

A(s) = exact transform of the numerator, a(t)

B(s) = exact transform of the denominator, b(t)

A*(s) = transform of a(t) calculated by FREQUENCY RESPONSE

B*(s) = transform of b(t) calculated by FREQUENCY RESPONSE

From Equations (139) and (140),

$$\Big| |A| - |A^*| \Big| \le \epsilon_A t_n = \delta_A \tag{154}$$

and

$$\Big| |B| - |B^*| \Big| \le \epsilon_B t_n = \delta_B \quad . \tag{155}$$

Then

$$-\delta_A \le |A| - |A^*| \le \delta_A \tag{156}$$

so that

$$|A^*| - \delta_a \le |A| \le |A^*| + \delta_A \tag{157}$$

and

$$-\delta_B \le |B| - |B^*| \le \delta_B \tag{158}$$

so that

$$|B^*| - \delta_B \le |B| \le \delta_B + |B^*| \quad . \tag{159}$$

It follows that

$$\frac{|A^*| - \delta_a}{|B^*| + \delta_b} - \frac{|A^*|}{|B^*|} \leq \frac{|A|}{|B|} - \frac{|A^*|}{|B^*|} \leq \frac{|A^*| + \delta_a}{|B^*| - \delta_b} - \frac{|A^*|}{|B^*|} \quad . \tag{160}$$

This expression can be reduced to

$$- \frac{\frac{|A^*|}{|B^*|}\delta_b + \delta_a}{|B^*| + \delta_b} \leq \frac{|A|}{|B|} - \frac{|A^*|}{|B^*|} \leq \frac{\frac{|A^*|}{|B^*|}\delta_b + \delta_a}{|B^*| - \delta_a} \quad . \tag{161}$$

The output from FREQUENCY RESPONSE in this case will be A^*/B^*. To determine an error envelope, an additional run must be made to determine $|B^*|$. The quantities δ_a and δ_b are equal to $\epsilon_A t_n$ and $\epsilon_B t_n$, respectively. [See Equation (138) for definition of ϵ.] Using these values and Equation (161), an error envelope can be calculated.

The error in the calculated phase can be determined in a similar manner. From Equation (142) it is seen that, for a single integral, the phase error has the form

$$|\sin(\phi - \phi^*)| \leq K \quad . \tag{162}$$

Following the notation defined on page 40, the phase of A^*/B^* is

$$\phi^* = \phi_A{}^* - \phi_B{}^*$$

($\phi_A{}^*$ is the phase of A^*); and the phase error is

$$\phi - \phi^* = \phi_A - \phi_B - (\phi_A{}^* - \phi_B{}^*) = (\phi_A - \phi_A{}^*) - (\phi_B - \phi_B{}^*) \quad . \tag{163}$$

As before, it is convenient to consider

$$\sin(\phi - \phi^*)$$

rather than $(\phi - \phi^*)$. Note that

$$\sin(\phi - \phi^*) = \sin(\phi_A - \phi_A{}^*)\cos(\phi_B - \phi_B{}^*) - \cos(\phi_A - \phi_A{}^*)\sin(\phi_B - \phi_B{}^*) \tag{164}$$

and

$$|\sin(\phi - \phi^*)| \leq |\sin(\phi_A - \phi_A{}^*)| + |\sin(\phi_B - \phi_B{}^*)| \leq k_A + k_B \tag{165}$$

where, by Theorem IV,

$$k_A \geq \frac{\epsilon_A t_n}{|A^*|}$$

and

$$k_B \geq \frac{\epsilon_B t_n}{|B^*|} \quad .$$

Thus,

$$|\sin(\phi - \phi^*)| \leq \left(\frac{1}{|B^*|} \frac{|B^*|}{|A^*|} \epsilon_A t_n + \epsilon_B t_n \right) . \qquad (166)$$

Again, to find the maximum error envelope, an additional run is required to determine $|B^*|$.

This argument has been made by applying Theorem III. It should be noted that a similar argument could be made using Theorem V. Application of Theorem V will result in the replacement of ϵ_A and ϵ_B by $\frac{\epsilon_m A}{\omega}$ and $\frac{\epsilon_m B}{\omega}$ throughout the above discussion. (See Theorem V, page 36 , for the definition of ϵ_m.)

III. INPUT FORMAT

1. INTRODUCTION

The data preparation routines and the three major programs SMOOTH, REACTIVITY, and FREQUENCY RESPONSE of SPORT may be used either separately or in sequence to process data recorded either on tape or on cards. Due to the various ways data may be processed, it is necessary that a number of options be made available to the user. These options, the necessary control cards, and the control card sequence are described in this section.

Subsection 2 of this section, Data System Options, is subdivided into five major parts: (a) Description of types of data which may be processed; (b) Options available in the Data Preparation phase of SPORT; (c) Options available in SMOOTH; (d) Options available in REACTIVITY; and (e) Options available in FREQUENCY RESPONSE. Options discussed in each part include input options, processing options, and output options.

Subsection 3, System Control Cards, is subdivided into two major parts: (a) general control cards and (b) program control cards. The type of data to be processed, the initial data preparation and output of raw or prepared data, and the major programs to be applied to the data are specified with the general control cards. Processing by the major programs (including output options) is controlled by the program control cards.

Subsection 4, Card Sequence, is a description of the cards which must be used and the proper sequence for processing data.

If it is desired to use the various plotting options described in this chapter, SPORT must be adopted to the digital plotting facilities available.

The routine "PLOT" supplied in binary form in the standard SPORT program deck will generate plot tapes for use on an IBM-1401 Computer with attached CALCOMP (California Computing Products Company) series 500 incremental digital plotter.

This PLOT routine should be replaced by an equivalent routine which will perform the functions assigned to PLOT in the CALCOMP plotting manual "SCOOP" and which will produce plot tapes in the proper form. The entry point "FINI" in PLOT should close out and unload the plot tape.

2. DATA SYSTEM OPTIONS

2.1 Types of Data That May Be Processed

2.11 Type 0 Data: Card Data Output From SMOOTH to be entered into REACTIVITY or card output from REACTIVITY to be entered into FREQUENCY RESPONSE.

2.12 Type 1 Data: Card Data In Spert 1-3 Form. The format of Spert 1-3 data is as follows: A 10-digit integer identification number in Columns 1 through 10, a 6-digit integer time value in Columns 13 through 18, and as many as six 3-digit integer data values in Columns 26 through 28, 36 through 38, ... , 76 through 78, with the signs of the data values being in Columns 29, 39, ... , 79. Data values not used may be left completely blank but a data value that is used may not contain blank columns.

2.13 Type 2 Data: Card Data In 650 Floating-Point Form with a 10-digit integer identification number in Columns 1 through 10. The time value must be in columns 11 through 20 and the 1 to 6 data channel values in Columns 20 through 30, 31 through 40, . . . , 71 through 80, all in 650 floating-point form.

2.14 Type 3 Data: Type 2 Data With a Sign Over-Punched In Column 10.

2.15 Type 3 Data: Card Data To Be Read In Under A Specified Format.

Each data card must have an integer identification number and a time value, in that order, preceding the first data value. A maximum of six data channels per card may be used. With these restrictions, data in any form which can be described by a single-precision FORTRAN format statement may be read into the system.

2.16 Type 5 Data: Data stored on a magnetic tape in 2000-point, 2021-word, FORTRAN Type 3 records. (See IBM 7040 Programmer's Guide: FORTRAN Files.) The 15th word in each record may be an integer number indicating the order of the records on the tape. The 17th word in each record must be an integer identification number, the 18th word the initial time, and the 19th word the time increment between successive data points in the record. The 20th through 2019th words in each record must contain the 2000 data values. A "channel" of Type 5 data on a magnetic tape may consist of any number of 2000-point data records with the same identification number logically arranged on the tape in order of increasing time. In Appendix C, an example is given of the type of scheme that should be used to convert data to SPORT Type 5 data. Appendix C contains a listing of a program which may be used to generate Type 5 data.

2.17 Data Time Sequence. The SPORT data cards (data Types 1, 2, 3 and 4) must be arranged in order of increasing time. No two data cards may have the same time value.

2.2 Options Available in the Data Preparation Phase

2.21 Input Options. Data Types 1, 2, 3, 4, and 5 may be used as input in the Data Preparation phase of SPORT.

2.22 Processing Options.

(1) Data Normalization. Each channel of data used in a problem may be individually normalized according to the following scheme.

Normalized time value = (original time value times normalizing coefficient for time) + time shift.

Normalized data value = (original data value times normalizing coefficient for data) + data shift.

(2) Data Compositing. The normalized data channels used in a problem may be combined into a single "composite" data channel during data preparation.

(3) Logarithmic Conversion. The normalized data to be used in a problem may be converted into natural logarithmic form during data preparation.

2.23 Output Options.

(1) Data listing and card output. The prepared data may be listed in decimal form. In addition, the prepared data may be punched out on IBM cards, one data value per card, in exponential and normalized decimal form.

(2) Plots of prepared data. The prepared data may be plotted in semilog or linear form.

2.3 Options Available in the SMOOTH Program

2.31 Input Options. Data Types 1, 2, 3, 4 and 5. Data which is to be smoothed for use in the REACTIVITY program must be in natural logarithmic form.

2.32 Processing Options. Input data may be smoothed on any odd number of points from 3 to 99 inclusive. One set of data may be resmoothed as many as 9 times. It should be noted that if the input data are separated by equal time increments and if the output values have this same time increment, the time required to smooth a set of data will be reduced by approximately one-third.

2.33 Output Options. The SMOOTH output listing and SMOOTH output cards are optional. A binary output tape for use as input to other programs is optional. Linear or semilog plots of coefficient C and linear plots of coefficient B are optional. Plot size, scaling, and range of data plotted may be designated.

2.4 Options Available in the REACTIVITY Program

2.41 Input Options. Input to the REACTIVITY program may be in two forms: (a) input data which are processed in sequence by the SMOOTH and REACTIVITY programs or (b) direct card input.

2.42 Processing Options. Up to 50 delayed neutron groups may be used. Initial delayed neutron precursor concentrations may be read in or calculated by the program. The initial energy may be read in or calculated and a neutron source term may be specified.

2.43 Output Options. The REACTIVITY output listing and output cards are optional. Plots of power, reactivity, and energy are optional. Form (linear or semilog), size, scaling, and range of data plotted may be designated.

2.5 Options Available in the FREQUENCY RESPONSE Program

2.51 Input Options. Input to the FREQUENCY RESPONSE program may be in several forms: (a) input data processed in sequence by the REACTIVITY and FREQUENCY RESPONSE programs, (b) input data processed in sequence by the SMOOTH and FREQUENCY RESPONSE programs, (c) Type 5 (tape) data, or (d) direct card input.

2.52 Processing Options. Frequencies may be entered in rad/sec or in cps. The transform of a single data trace or the ratio of transforms of two data traces may be calculated. The input data may be multiplied by an exponential function of time. Two traces of input data may be smoothed and then processed simultaneously, one as the numerator and the other as the denominator in the ratio of transforms. Alternately, the difference between data values in the two traces may be calculated, and the transform of this difference used as the numerator and the transform of one of the two channels as the denominator in the ratio of transforms.

2.53 Output Options. Card output and plots of the magnitude and phase of the FREQUENCY RESPONSE output are optional.

3. SYSTEM CONTROL CARDS

The system control cards may be divided into two categories: (a) general control cards and (b) program control cards. The general control cards serve to initiate processing while the program control cards control the actual processing of the data with the various programs.

3.1 General Control Cards

3.11 PART Card. The PART card serves to (a) designate the programs that will be applied to the data and (b) to control the data preparation portion of the processing.

(1) Column 1; Basic Processing Scheme.

Blank or zero: Data preparation only (as described under DATA SYSTEMS OPTIONS, Subsection 2.2).

One: Data preparation and SMOOTH.

Two: Data preparation, SMOOTH and REACTIVITY. REACTIVITY results are then available (in the computer) as input to FREQUENCY RESPONSE (see column 2 below).

Three: Data preparation and SMOOTH. SMOOTH results are then available (in the computer) as input to FREQUENCY RESPONSE (see column 2 below).

Four: Direct card input (no preparation) into REACTIVITY. REACTIVITY results are then available (in the computer) as input to FREQUENCY RESPONSE (see column 2 below).

Five: Case 1 -- For data Types 0, 2, 3 and 4: direct card input (no preparation) to FREQUENCY RESPONSE. Case 2 -- For data Type 5: Data preparation. The prepared data is then available as input to FREQUENCY RESPONSE.

(2) Column 2: Processing with Frequency Response. (Column 2 has significance only if a 2, 3, 4, or 5 is entered in Column 1.)

Blank or zero: No processing with FREQUENCY RESPONSE.

One: Data will be processed with FREQUENCY RESPONSE.

(3) Column 3: Data Type (as described in Subsection 2).

(4) Columns 4, 5, and 6: Number of data Channel Sections to be Used in the Problem. If each channel section is to be processed separately as indicated by Columns 1 and 2, this number must be positive. If the channel sections are to be composited into a single data curve and then processed, this number must be negative.

(5) Column 7: Output of Data Before Processing with Principal Programs.

Blank or zero: No data output.

One: Listing of prepared data.

Two: Listing and card output of prepared data.

(6) Column 8: Logarithmic Conversion

Blank or zero: Input data will remain in original form.

One: Natural logarithm of normalized input data will be processed.

(7) Column 9: Reserved for Additional Options. Should be left blank.

(8) Column 10: Plots of Data before Processing with Principal Programs.

Blank or zero: No plots.

One: 10- by 7-inch semilog plots. (10-inch abscissa, 7-inch ordinate)

Two: 10- by 7-inch linear plots. (10-inch abscissa, 7-inch ordinate)

(A two should be entered if the data were originally in logarithmic form.)

(9) Columns 11 through 72: Problem Title. Used to head each page in the problem output and to title all normalized data plots.

3.12 CHANNEL Card. The purpose of the CHANNEL card is to control the selection and normalization of a section from a single channel of input data. If a composite data channel is to be formed during data preparation, the CHANNEL card must also specify the position of the section in the composite channel.

(1) Columns 1 through 10: Channel Identification Number. Card data (Types 1 through 4): Columns 1 through 9 are left blank, and the channel number of the data to be processed is entered in Column 10. The channel number of data in word three on the data cards is 1, that of word four is 2, and so on up to a maximum of 6 channels per card. Tape data (Type 5). Columns 1 through 10 must contain the identification number that is stored in the 17th word of the data record.

(2) Columns 11 through 30: (Floating point) Time range in which data are to be made available for processing.

Minimum time: Columns 11 through 20 (assumed zero if left blank).

Maximum time: Columns 21 through 30 (assumed 10^{30} if left blank).

(3) Columns 31 through 50: (Floating point) Normalizing Coefficient as defined by Equation (1). (Applied before correctional shifts entered in Columns 51 through 70.)

Normalizing coefficient for time: Columns 31 through 40. (Assumed one if left blank.)

Normalizing coefficient for data: Columns 41 through 50. (Assumed one if left blank.)

(4) Columns 51 through 70: (Floating point) Correctional Shifts as defined by Equation (1). (Applied to normalized time and data values.)

Time shift: Columns 51 through 60. (Assumed zero if left blank.)

Data shift: Columns 61 through 70. (Assumed zero if left blank.)

(5) Columns 71 through 74: Data Reel Number (Type 5 data only). If the reel number of the data tape is known, it should be entered on the first CHANNEL Card. If not, Columns 71 through 74 should be left blank, and the data tape will be called for by the Channel Identification Number on the first CHANNEL Card.

(6) Columns 75 through 78: File Index Number (Type 5 data only). The index number (word 15 in a SPORT Type 5 data record) may be entered if it is necessary to distinguish between several data records with the same identification number.

3.13 FORMAT Card. The purpose of the FORMAT card is to specify how Type 4 data values (see Subsection 2.1) are arranged on the data cards.

(1) Column 1: The number of data channel values per card.

(2) Columns 2 through 80: A single-precision FORTRAN format statement, excluding the word "FORMAT". This format statement must describe the form and arrangement of the identification number, time value, and 1 to 6 data channels.

3.14 END-OF-DATA Card. The purpose of the END-OF-DATA card is to indicate that the preceding card was the last card in the data deck. It is simply a blank card.

3.15 INPUT Card. The purpose of the INPUT card is to identify card data which is to be read directly into the REACTIVITY or FREQUENCY RESPONSE subroutines.

(1) Columns 1 through 10: Identification Number on the data cards.

(2) Columns 11 through 20: (Floating point) Time Increment between successive data cards.

3.16 CONTINUE Card. The purpose of the CONTINUE card is to indicate that at the completion of the current problem, processing is to continue on a new problem. This card contains *CONTINUE starting in Column 1.

3.17 STOP Card. The purpose of the STOP card is to indicate that at the completion of the current problem, processing is to stop and that the plot tape is to be closed out and unloaded. This card contains *STOP starting in Column 1.

3.2 Program Control Cards

3.21 SMOOTH TITLE Card. The purpose of the SMOOTH TITLE Card is to title and identify the SMOOTH output. It may contain any characters in column 2 through 80.

3.22 SMOOTH CONTROL Card. The purpose of the SMOOTH CONTROL Card is to control the processing done by SMOOTH.

(1) Columns 1 through 10: Identification Number of the Data.

(2) Columns 11 through 20: (Floating point) Time Step between Output Points.

(3) Columns 21 through 40: (Floating point) Time Range. Data at time values less than the value listed in Columns 21 through 30 will be ignored.

(4) Columns 41 through 60: (Floating point) Time for First SMOOTH Calculation. Columns 41 through 50 contain the value (on the input data time scale) at which the first SMOOTH calculation will be made. If this value is left blank (or is too small), the minimum possible time value will be used. Columns 51 through 60 contain the value that will be given to the first point in the output data. If the value in Columns 41 through 50 is reset, the value in Columns 51 through 60 will also be reset to maintain the same shift.

(5) Columns 61 through 62: Number of Points on which to Smooth. (May be any odd number from 3 to 99, inclusive.)

(6) Column 63: Output Control.

0: Listing

1: Listing and cards

3: No listing or card output.

(7) Column 64: Type of Plot.

0: No plots

1: Semilog plot of coefficient C.

2: Linear plot of coefficient C.

3: Semilog plot of coefficient C with a linear plot of coefficient B superimposed.

4: Linear plot of coefficient C with a linear plot of coefficient $\bar{B}$ superimposed.

(8) Column 65: Form of Data to be Plotted.

0: Data is log-base-e.

2: Data is linear.

(9) Column 66: Plot Size and Scaling Control. A non-zero integer in Column 66 indicates that a SMOOTH Plot Scaling Card will follow the SMOOTH Control Card.

(10) Column 68: Number of Smoothing Passes to be made. If Column 68 is left blank, one pass will be made. All the available data that lies in the time range specified in Columns 21 through 40 will be smoothed in preliminary passes. All the SMOOTH output options will be suppressed until the final pass.

(11) Column 69: Binary Tape Output. (May be ignored if binary tape is not desired.)

1: Binary tape will be rewound before writing.

2: Binary tape will not be rewound before writing.

(12) Column 70: Binary Tape Unload. A non-zero integer in Column 70 will cause the binary tape to unload. The last data record on the tape will be followed by a record with its first word set to 20000000002 and then an end-of-file mark.

3.23 SMOOTH PLOT SCALING Card: The purpose of the SMOOTH PLOT SCALING Card is to provide various sizes of SMOOTH plots. (See Column 66, SMOOTH CONTROL Card.)

(1) Columns 1 through 20: (Floating point) Abscissa Scaling. (Optional; must be in linear form.)

1 through 10: Minimum value on abscissa.

11 through 20: Maximum value on abscissa.

(2) Columns 21 through 40: (Floating point) Ordinate Scaling. (Optional; must be in linear form for a linear plot or log-base-10 form for a semilog plot.)

21 through 30: Minimum value on ordinate.

31 through 40: Maximum value on ordinate.

(3) Columns 41 through 60: (Floating point) Scaling Coefficient B. (Optional; must be in linear form.)

41 through 50: Minimum value on B axis.

51 through 60: Maximum value on B axis.

(4) Columns 61 through 64: Plot Size (Optional; assumed 10-inch abscissa, 7-inch ordinate if left blank.)

61 through 62: Length of abscissa in inches (Minimum 3-inches, maximum 99-inches).

63 through 64: Length of ordinate in inches (Minimum 3-inches, maximum 26-inches).

3.24 REACTIVITY TITLE Card. The purpose of the REACTIVITY TITLE Card is to identify output from REACTIVITY. It may contain any characters in Columns 2 through 80.

3.25 REACTIVITY CONTROL Card. The purpose of the REACTIVITY CONTROL Card is to control input and output procedures and supply certain basic parameters.

(1) Columns 1 through 10: (Floating point) Λ/β. (See definitions page 18).

(2) Columns 11 through 20. (Floating point) α_i, The Initial Reciprocal Period.

(3) Columns 21 through 22. The Number of Delayed Neutron Groups.

(4) Column 23. Initial Precursor Concentrations

0: REACTIVITY calculates concentrations.

1: Concentrations to be furnished as input.

(5) Column 24. Output Control

0: Listing of output.

1: Listing and card output.

3: No listing or card output.

(6) Column 25. Initial Energy

0: Initial energy will be calculated.

1: Initial energy will be supplied in Columns 31 through 40.

(7) Columns 26 through 28. Plot Control. In each column, a 1 indicates a semilog plot while a 2 indicates a linear plot of the corresponding parameter.

Column 26: Linear power.

Column 27: Reactivity.

Column 28: Energy.

(8) Column 29. Plot Size and Scaling Control. A non-zero integer indicates that a REACTIVITY PLOT SCALING Card will follow the REACTIVITY Control Card.

(9) Columns 31 through 40. (Floating point) Initial Energy (see Column 25).

(10) Columns 41 through 50. (Floating point) Source Term (must be entered in units of power per unit time).

3.26 REACTIVITY PLOT SCALING Card. The purpose of the REACTIVITY PLOT SCALING Card is to provide various size plots of the output from REACTIVITY.

(1) Columns 1 through 10. (Floating point) Abscissa Scaling in Power Plot. (Optional, may be left blank.)

1 through 5: Minimum abscissa value.

6 through 10: Maximum abscissa value.

(2) Columns 11 through 20. (Floating point) Ordinate Scaling in Power Plot. (Optional; must be in linear form for a linear plot; or log-base-10 form for a semilog plot.)

11 through 15: Minimum ordinate value.

16 through 20: Maximum ordinate value.

(3) Columns 21 through 24. Plot Size for Power Plot. (Assumed 10-inch abscissa, 7-inch ordinate if left blank.)

21 through 22; Length of abscissa in inches. (minimum 3-inches, maximum 99-inches.

23 through 24: Length of ordinate in inches (minimum 3-inches, maximum 26-inches).

(4) Columns 26 through 35. (Floating point) Abscissa Scaling in Reactivity Plots (Optional).

26 through 30: Minimum abscissa value.

31 through 35: Maximum abscissa value.

(5) Columns 36 through 45. (Floating point) Ordinate Scaling in Reactivity Plots. (Optional; form must agree with that of the plot.)

36 through 40: Minimum ordinate value.

41 through 45: Maximum ordinate value.

(6) Columns 46 through 49. Plot Size for Reactivity Plot. (Assumed 10-inch abscissa, 7-inch ordinate if left blank.)

46 through 47: Length of abscissa in inches (minimum 3-inches, maximum 99-inches).

48 through 49: Length of ordinate in inches (minimum 3-inches, maximum 26-inches).

(7) Columns 51 through 60. (Floating point) Abscissa Scaling in Energy Plots (optional).

51 through 55: Minimum abscissa value.

56 through 60: Maximum abscissa value.

(8) Columns 61 through 70. (Floating point) Ordinate Scaling in Energy Plots. (Optional; form must agree with that of the plot.)

61 through 65: Minimum ordinate value.

66 through 70: Maximum ordinate value.

(9) Columns 71 through 74. Plot Size for Energy Plots. (Assumed 10-inch abscissa, 7-inch ordinate if left blank.)

71 through 72: Length of abscissa in inches (minimum 3-inches, maximum 99-inches).

73 through 74: Length of ordinate in inches (minimum 3-inches, maximum 26-inches).

3.27 LAMBDA Card. (Floating point) The purpose of the LAMBDA Card is to enter the decay constants of the delayed neutron groups. The decay constants are entered, eight per card, in ten column fields.

3.28 F Card. (Floating point) The purpose of the F Card is to enter the values of f_i for each delay group. The values of f_i are entered eight per card in ten column fields.

3.29 W Card. (Floating point) The purpose of the W Card is to enter the initial values of W_i if this option is chosen. (See Column 23 of the REACTIVITY CONTROL Card.) The values of W_i (see definitions, page 18) are entered eight per card in ten column fields.

3.210 FREQUENCY RESPONSE TITLE Card. The purpose of the FREQUENCY RESPONSE TITLE Card is to identify the FREQUENCY RESPONSE output. It may contain any characters in Columns 2 through 80.

3.211 FREQUENCY RESPONSE CONTROL Card. The purpose of the FREQUENCY RESPONSE CONTROL Card is to control the options available in this program.

(1) Columns 1 through 3: Number of Frequencies

(2) Column 4: Word [a] which Contains the Numerator.

(3) Column 5: Word [a] which Contains the Denominator.

---

[a] Significance of numerator and denominator word numbers.

REACTIVITY output

Word 1: linear power
Word 2: reactivity
Word 3: compensated reactivity
Word 4: energy
Word 5: shutdown coefficient (see page 22)

SMOOTH output

Word 1: coefficient C (smoothed data value)
Word 2: coefficient B (slope of smoothed data)
Word 3: coefficient A

Direct card input

Word 1 corresponds to the first data value on the card, word 2 to the second, etc.

(4) Column 6: Ratio Control

1: The ratio of the transform of the numerator to the transform of the denominator will be calculated.

2: Only the transform of the numerator will be calculated.

3: Two data traces are smoothed, and the first run is used as the numerator while the second run is used as the denominator.

4: Same as Option 3 except the denominator is first subtracted from the numerator and then the ratio is calculated.

(5) Column 7: Plot Control

1: Plot of only the magnitude of the results.

2: Plot of both the magnitude and the phase of the results.

(6) Column 8: Card Output

Card output of results is obtained by entering a non-zero integer in Column 8.

(7) Column 9: Units Control

0: Frequencies will be entered in radians per second.

1: Frequencies will be entered in cycles per second.

(8) Columns 21 through 30: Alpha. If a non-zero, floating point quantity α is entered in Columns 21 through 30, the input values will be multiplied by $\exp(-\alpha t)$.

3.212 OMEGA Card. (Floating point) The purpose of the OMEGA Card is to enter the values of the frequencies at which calculations will be made. These values are entered eight per card in the ten column fields.

4. CARD SEQUENCE

(1) A PART Card is always the first control card in any problem.

(2) The CHANNEL Card(s) follow the PART Card. Up to 50 CHANNEL Cards may be used.

For individual processing of several channels of data [a], N, the value entered in Columns 4, 5, and 6 on the PART Card should be positive, and there should be one CHANNEL Card for each channel of data to be processed.

For assembly of the prepared data into a composite channel [a], N, should be negative, and there should be one CHANNEL Card for each section of data to be incorporated in the composite channel. The order of the CHANNEL Cards must be the order in which the sections are to be assembled. Time values on CHANNEL Cards must be in the normalized and shifted time scale and must form a logical sequence. Data may be eliminated by entering a large time shift on the corresponding CHANNEL Card. An INPUT card replaces the set of N CHANNEL Cards in the special case of card data which are to be entered directly into the REACTIVITY or FREQUENCY RESPONSE Program.

(3) FORMAT Card (Type 4 data only).

(4) DATA DECK (data Types 0, 1, 2, 3, and 4)

(5) END-OF-DATA Card (data Types 0, 1, 2, 3, and 4)

(6) Program Control Card Sets. A Program Control Card Set contains either all the Program Control Cards necessary to process one of the N individual channels specified on the CHANNEL Cards or all the Program Control Cards necessary to control the processing of the one composite channel formed during data preparation.

If N (Columns 4, 5, and 6 on PART card) is positive, N sets of Program Control Cards are needed, in the same order as and corresponding to, the N CHANNEL cards.

If N is negative, only one set of Program Control Cards is needed.

(a) SMOOTH Program: The control card sequence necessary to control data smoothing is

SMOOTH Title card

SMOOTH Control Card

SMOOTH Plot Scaling Card (Used only if Column 66 on the SMOOTH Control Card contains a non-zero integer.)

---

[a] Data Availability

1. Data Types 1, 2, 3 and 4 (card data): Any of the data channels on the data channels on the data cards may be selected on any of the CHANNEL Cards.

2. Data Type 5 (tape data): Any of the data channels stored in the data tape may be selected except those that precede the channel specified on the first CHANNEL Card. The first CHANNEL Card may be a "dummy" that serves only to position the data tape. In this case, the minimum and maximum times entered on the first CHANNEL Card should be the same as the minimum time entered on the second CHANNEL Card.

(b) REACTIVITY Program: The control card sequence necessary to calculate reactivity and energy from SMOOTH data is

REACTIVITY Title Card

REACTIVITY Control Card

REACTIVITY Plot Scaling Card (Used only if Column 29 on the REACTIVITY Control Card contains a non-zero integer.)

LAMBDA Card(s)

F Card(s)

W Card(s) (Used only if Column 23 on the REACTIVITY Control Card is non-zero.)

(c) FREQUENCY RESPONSE Program: The necessary control card sequence is

FREQUENCY RESPONSE Title Card

FREQUENCY RESPONSE Control Card

OMEGA Card(s)

(7) PROBLEM TERMINATION Card (The last card in any problem).

CONTINUE Card: Used if another problem follows the current one.

STOP Card: Used if the current problem is the last one to be processed.

IV. OUTPUT FORMAT

1. INTRODUCTION

The SPORT processing system generates output in four forms: (a) output listings, (b) punched output on cards, (c) CALCOMP computer plots, and (d) output in binary form on tape. In this section, the form and arrangement of output generated by SPORT in the data preparation section and in the SMOOTH, REACTIVITY, and FREQUENCY RESPONSE programs are described.

2. DATA PREPARATION OUTPUT

The PART card and the CHANNEL cards or INPUT card are listed on the first page in the SPORT output (page 59). Next (if called for), is a listing of the input data in final normalized form (page 60). The normalized data is punched on cards in the format:

(I10, 5X, F12.6, 5X, E14.7, 5X, F20.8)

where the first quantity is the identification number, the second the time value, and the third and fourth the data value in exponential and normalized decimal form, respectively.

Figure 13 is an example of a SPORT normalized data plot.

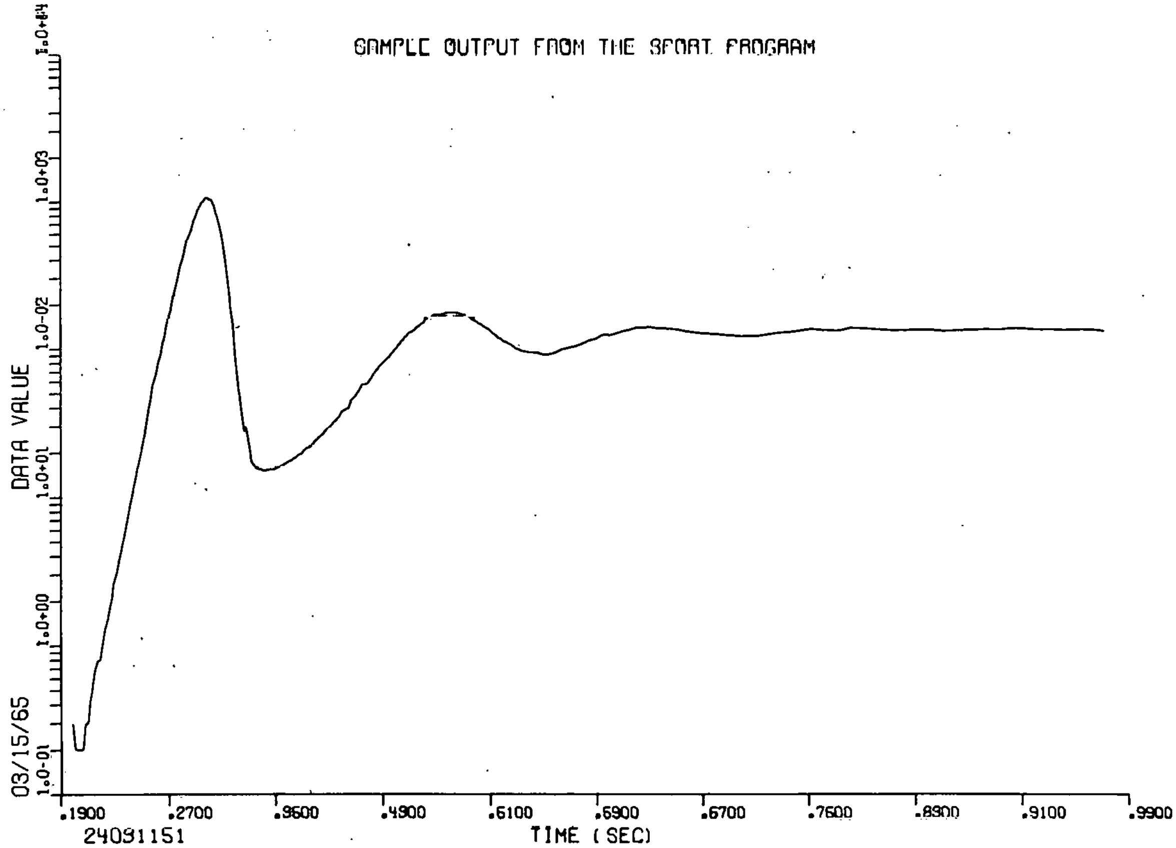

Fig. 13 Plot of power data as prepared by the SMOOTH program.

SPORT 03/15/65 SYSTEM FOR PROCESSING REACTOR TRANSIENT DATA

PART CARD WAS 211 -71101 SAMPLE OUTPUT FROM THE SPORT PROGRAM

CHANNEL ID NO	FILE NO (IF ANY)	MINIMUM TIME	MAXIMUM TIME	NORMALIZING COEFFICIENTS TIME	NORMALIZING COEFFICIENTS DATA	TIME SHIFT	DATA SHIFT
3	-0	-0.	0.255000	0.000100	1.0000000E-01	-0.	-0.
5	-0	0.255000	0.280000	0.000100	1.0000000E 00	-0.	-0.
6	-0	0.280000	0.313000	0.000100	1.0000000E 01	-0.	-0.
5	-0	0.313000	0.333000	0.000100	1.0000000E 00	-0.	-0.
3	-0	0.333000	0.399000	0.000100	1.0000000E-01	-0.	-0.
5	-0	0.399000	1.023000	0.000100	1.0000000E 00	-0.	-0.
3	-0	1.023000	X.XXXXXX	0.000100	1.0000000E-01	-0.	-0.

NORMALIZED COMPOSITE DATA 24031151

LN(DATA) TAKEN IN INPUT SUBROUTINE

0.200000	-1.204E 00	0.278900	5.838E 00	0.344000	2.728E 00	0.455500	4.942E 00	0.700000	4.812E 00
0.202000	-1.609E 00	0.280100	5.940E 00	0.346500	2.747E 00	0.458000	4.984E 00	0.709800	4.820E 00
0.204100	-1.609E 00	0.281100	6.016E 00	0.348300	2.741E 00	0.460000	5.017E 00	0.719800	4.852E 00
0.205400	-1.609E 00	0.282500	6.109E 00	0.350000	2.747E 00	0.462800	5.081E 00	0.729700	4.875E 00
0.207500	-1.609E 00	0.284000	6.292E 00	0.352600	2.773E 00	0.465100	5.100E 00	0.739600	4.890E 00
0.209300	-1.204E 00	0.286000	6.380E 00	0.354500	2.797E 00	0.468000	5.142E 00	0.749600	4.934E 00
0.211000	-1.204E 00	0.287800	6.492E 00	0.356300	2.815E 00	0.470100	5.159E 00	0.759600	4.913E 00
0.212300	-9.163E-01	0.289200	6.607E 00	0.358200	2.839E 00	0.472500	5.153E 00	0.769900	4.898E 00
0.214000	-6.931E-01	0.290600	6.685E 00	0.360000	2.862E 00	0.475000	5.159E 00	0.780000	4.949E 00
0.216300	-3.567E-01	0.292300	6.791E 00	0.362300	2.890E 00	0.477400	5.182E 00	0.790100	4.942E 00
0.218300	-2.231E-01	0.293600	6.835E 00	0.364000	2.912E 00	0.480100	5.193E 00	0.800000	4.927E 00
0.220000	-2.231E-01	0.294900	6.888E 00	0.366200	2.944E 00	0.483600	5.182E 00	0.810000	4.913E 00
0.222200	9.531E-02	0.296400	6.928E 00	0.368100	2.976E 00	0.487200	5.176E 00	0.820000	4.920E 00
0.223600	2.624E-01	0.297900	6.985E 00	0.370000	2.996E 00	0.490100	5.147E 00	0.830000	4.927E 00
0.225400	4.055E-01	0.299000	6.975E 00	0.371800	3.040E 00	0.494000	5.130E 00	0.840000	4.920E 00
0.227200	5.878E-01	0.299800	6.975E 00	0.373600	3.073E 00	0.497100	5.075E 00	0.850000	4.905E 00
0.228800	7.419E-01	0.300400	6.947E 00	0.375800	3.096E 00	0.500000	5.043E 00	0.860000	4.920E 00
0.230500	9.933E-01	0.301800	6.947E 00	0.378000	3.131E 00	0.505700	4.970E 00	0.870000	4.927E 00
0.232500	1.131E 00	0.302700	6.928E 00	0.379900	3.186E 00	0.510300	4.898E 00	0.880000	4.934E 00
0.234600	1.386E 00	0.303700	6.888E 00	0.382500	3.235E 00	0.515500	4.804E 00	0.890000	4.927E 00
0.236300	1.548E 00	0.304800	6.835E 00	0.384100	3.266E 00	0.520400	4.736E 00	0.900000	4.949E 00
0.238200	1.740E 00	0.306200	6.709E 00	0.385800	3.300E 00	0.525300	4.691E 00	0.910000	4.942E 00
0.239600	1.887E 00	0.307300	6.659E 00	0.388400	3.360E 00	0.530300	4.615E 00	0.920000	4.927E 00
0.241200	2.054E 00	0.308400	6.551E 00	0.389900	3.388E 00	0.535400	4.575E 00	0.930000	4.934E 00
0.242900	2.230E 00	0.309200	6.492E 00	0.392300	3.440E 00	0.540100	4.554E 00	0.940000	4.920E 00
0.244800	2.434E 00	0.310200	6.380E 00	0.394400	3.487E 00	0.545000	4.554E 00	0.950100	4.934E 00
0.246600	2.639E 00	0.311300	6.273E 00	0.396400	3.529E 00	0.550000	4.522E 00	0.960000	4.927E 00
0.247600	2.728E 00	0.312500	6.109E 00	0.398000	3.561E 00	0.554800	4.533E 00	0.970100	4.905E 00
0.248700	2.839E 00	0.313300	5.996E 00	0.400000	3.638E 00	0.559900	4.564E 00	X.XXXXXX	0.
0.250600	3.025E 00	0.315200	5.652E 00	0.403500	3.689E 00	0.565100	4.615E 00		
0.252300	3.199E 00	0.316400	5.460E 00	0.405400	3.689E 00	0.569900	4.635E 00		
0.253100	3.285E 00	0.317700	5.204E 00	0.407600	3.829E 00	0.574900	4.663E 00		
0.254000	3.378E 00	0.319000	4.977E 00	0.410000	3.871E 00	0.580000	4.700E 00		
0.255200	3.526E 00	0.319900	4.736E 00	0.413100	3.970E 00	0.585000	4.754E 00		
0.256400	3.689E 00	0.320900	4.533E 00	0.415400	4.060E 00	0.590100	4.779E 00		
0.257600	3.807E 00	0.323700	3.989E 00	0.417800	4.060E 00	0.595500	4.844E 00		
0.259300	4.043E 00	0.324800	3.829E 00	0.420000	4.094E 00	0.600000	4.828E 00		
0.261000	4.174E 00	0.325700	3.689E 00	0.422800	4.174E 00	0.605200	4.860E 00		
0.262300	4.290E 00	0.326700	3.526E 00	0.425300	4.263E 00	0.610000	4.890E 00		
0.263800	4.454E 00	0.328100	3.332E 00	0.427800	4.331E 00	0.615000	4.920E 00		
0.265100	4.522E 00	0.329200	3.401E 00	0.429900	4.382E 00	0.619900	4.949E 00		
0.266700	4.710E 00	0.330500	3.296E 00	0.432800	4.443E 00	0.625100	4.949E 00		
0.267800	4.796E 00	0.332200	3.045E 00	0.435200	4.489E 00	0.629800	4.956E 00		
0.269200	4.949E 00	0.333600	2.851E 00	0.438000	4.554E 00	0.635100	4.934E 00		
0.270900	5.100E 00	0.335100	2.809E 00	0.440000	4.605E 00	0.639800	4.934E 00		
0.272200	5.209E 00	0.337100	2.754E 00	0.442600	4.682E 00	0.649700	4.920E 00		
0.273600	5.357E 00	0.338600	2.747E 00	0.445200	4.745E 00	0.659700	4.875E 00		
0.275100	5.505E 00	0.339900	2.734E 00	0.448000	4.812E 00	0.669800	4.852E 00		
0.276700	5.631E 00	0.340000	2.734E 00	0.450000	4.860E 00	0.680000	4.844E 00		
0.277900	5.740E 00	0.342000	2.721E 00	0.453500	4.905E 00	0.690000	4.820E 00		

DATA PREPARATION REQUIRED 0 MIN 46.8 SEC AND DATA PLOT REQUIRED 0 MIN 9.8 SEC

3. SMOOTH PROGRAM OUTPUT

The values on the SMOOTH CONTROL Card are listed on the first page in the SMOOTH program output in the same order in which they were entered (page 62). The labels identifying the code words entered in Columns 61 through 70 must be read from top to bottom. If the time at which the first SMOOTH calculation is to be made has to be reset, SMOOTH will print out the corrected value. The identification number, time, and coefficients, C, B, and A, may be listed at each output point, 50 points per page, and punched on cards in the format:

(I10, F16.6, 3F16.7) .

Pages 63 and 64 are examples of the first and last pages in the SMOOTH output listing.

The smoothed data values may be transferred in binary form to a special output tape. This tape contains a number of 400-word, FORTRAN Type 3 records. In the first record, only the first four words are significant. Word one is the integer identification number of the smoothed data; word two is the integer channel number; word three is the time increment in the smoothed data; and word four is the integer number of smoothed data points. The second and succeeding records contain the time value and coefficients, C, B, and A (in that order), for 100 successive data points. All of the 400 words in the last record may not be significant. Appendix C contains a listing of a program which may be used to read the binary tape generated by SMOOTH.

Figure 14 is an example of a SMOOTH output plot of coefficients C and B.

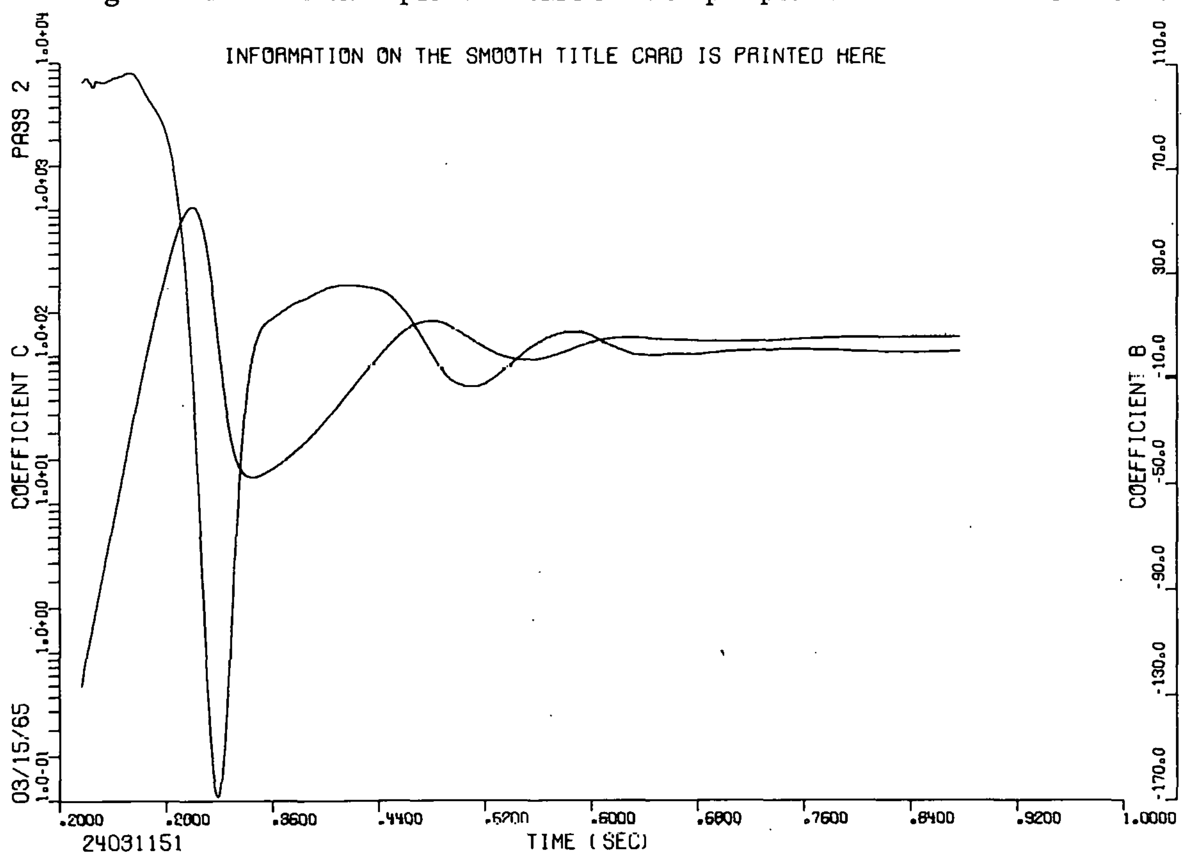

Fig. 14 Plot of power data and slope as prepared by the SMOOTH program.

```
QUADRATIC SMOOTHING PROGRAM                                                                          N L    S O R TD
                                                                                                     U I PDC R E RS
          INFORMATION ON THE SMOOTH TITLE CARD IS PRINTED HERE                                       M S LAA D C AM
                                                                                                     B T OTL E Y NN
PASS NUMBER 1              ID NO      DELTA T       T MINIMUM     T MAXIMUM     T START CAL   1ST OUTPUT T   R G TAE R L ST

SMOOTH CONTROL CARD WAS-  24031151      0.001000      -0.            -0.            -0.            -0.        21 0 300 0 2 00
CONTROL WORDS RESET    -                                                         0.217300       0.217300

CALCULATIONS REQUIRED        0 MIN 27.6 SEC

BEGIN PASS 2
CONTROL WORDS RESET    -                                                         0.217300       0.217300
```

SPORT 03/15/65 SAMPLE OUTPUT FROM THE SPORT PROGRAM

SMOOTH PROGRAM OUTPUT LISTING FOR CHANNEL 0

ID NUMBER	TIME	C	B	A
24031151	0.217300	-0.4996546	103.1513481	2257.1232910
24031151	0.218300	-0.3399733	103.7023516	874.3408203
24031151	0.219300	-0.2109451	104.1741114	207.8264160
24031151	0.220300	-0.0913869	104.3178101	-239.9172363
24031151	0.221300	0.0237759	104.1818142	-555.6202393
24031151	0.222300	0.1165129	102.7672749	-199.1550903
24031151	0.223300	0.2244377	102.8508348	-376.7765732
24031151	0.224300	0.3146244	101.1550493	74.2547607
24031151	0.225300	0.4124821	100.8328056	189.3391113
24031151	0.226300	0.5147860	101.3788919	143.3051758
24031151	0.227300	0.6272528	103.6343822	-307.3791504
24031151	0.228300	0.7265447	103.0831270	-123.3586426
24031151	0.229300	0.8283663	102.9740791	-68.7431641
24031151	0.230300	0.9295034	102.7939072	10.3012695
24031151	0.231300	1.0298466	102.5432405	115.5253906
24031151	0.232300	1.1313293	102.5753593	164.2382812
24031151	0.233300	1.2327661	102.6138821	216.6264648
24031151	0.234300	1.3353653	102.8016453	221.5419922
24031151	0.235300	1.4384027	103.0311441	216.0673828
24031151	0.236300	1.5427382	103.3143482	163.4516602
24031151	0.237300	1.6479278	103.6170912	85.4482422
24031151	0.238300	1.7522640	103.8473673	58.1206055
24031151	0.239300	1.8569342	104.1073437	26.7661133
24031151	0.240300	1.9621183	104.3871880	-15.6210937
24031151	0.241300	2.0666708	104.5208359	-20.0810547
24031151	0.242300	2.1709748	104.7135792	-5.9042969
24031151	0.243300	2.2748967	104.8554544	33.1259766
24031151	0.244300	2.3787201	104.9985676	83.0644531
24031151	0.245300	2.4825248	105.1213951	139.8642578
24031151	0.246300	2.5862420	105.2268457	205.7871094
24031151	0.247300	2.6909777	105.4858828	233.8730469
24031151	0.248300	2.7971041	105.8095922	212.2128906
24031151	0.249300	2.9039655	106.1084976	171.3818359
24031151	0.250300	3.0110043	106.2774277	133.1093750
24031151	0.251300	3.1184892	106.3675909	80.5078125
24031151	0.252300	3.2261320	106.3934708	23.3906250
24031151	0.253300	3.3339328	106.3542700	-41.1699219
24031151	0.254300	3.4418737	106.2259665	-115.8701172
24031151	0.255300	3.5496849	105.9564419	-193.6962891
24031151	0.256300	3.6573533	105.5618258	-280.0888672
24031151	0.257300	3.7641913	104.9732380	-351.1533203
24031151	0.258300	3.8698580	104.2437353	-399.0292969
24031151	0.259300	3.9749616	103.4585485	-455.6992187
24031151	0.260300	4.0792487	102.5253763	-514.3085937
24031151	0.261300	4.1820185	101.5158148	-548.2050781
24031151	0.262300	4.2831175	100.4835253	-552.6992187
24031151	0.263300	4.3829668	99.5045776	-546.1503906
24031151	0.264300	4.4817572	98.5055304	-536.4394531
24031151	0.265300	4.5791535	97.5833216	-507.1152344
24031151	0.266300	4.6754189	96.7018213	-467.4238281

SPORT 03/15/65 SAMPLE OUTPUT FROM THE SPORT PROGRAM

SMOOTH PROGRAM OUTPUT LISTING FOR CHANNEL 0

ID NUMBER	TIME	C	B	A
24031151	0.867300	4.9278864	0.1007919	12.4816895
24031151	0.868300	4.9285777	0.1961441	4.7578125
24031151	0.869300	4.9297699	0.4112244	-6.3645020
24031151	0.870300	4.9299526	0.3952179	-5.7084961
24031151	0.871300	4.9305982	0.4895706	-8.6699219
24031151	0.872300	4.9303113	0.3314590	-4.8402100
24031151	0.873300	4.9304335	0.2890320	-4.0540771
24031151	0.874300	4.9310476	0.3873062	-6.1068115
24031151	0.875300	4.9314288	0.3750916	-6.1068115
24031151	0.876300	4.9317978	0.3628769	-6.1066895

CALCULATIONS REQUIRED 0 MIN 34.4 SEC AND PLOT REQUIRED 0 MIN 25.0 SEC

4. REACTIVITY PROGRAM OUTPUT

The values on the REACTIVITY CONTROL Card are listed on the first page in the REACTIVITY program output in the same order in which they were entered (page 66). The labels identifying the code words entered in columns 21 through 30 must be read from top to bottom. The REACTIVITY PLOT SCALING Card (if used) is listed next, then the LAMBDA cards, the F cards, and, finally, the W cards (if any). The identification number, time, linear power, total reactivity, compensated reactivity, energy, and shutdown coefficient may be listed at each output point, 50 points to a page, and punched on cards in the format:

(I10, F10.6, F12.4, 2F12.6, F12.4, F12.8) .

Pages 67 and 68 are examples of the first and last pages in the REACTIVITY output listing.

Figures 15, 16, and 17 are examples of REACTIVITY output plots.

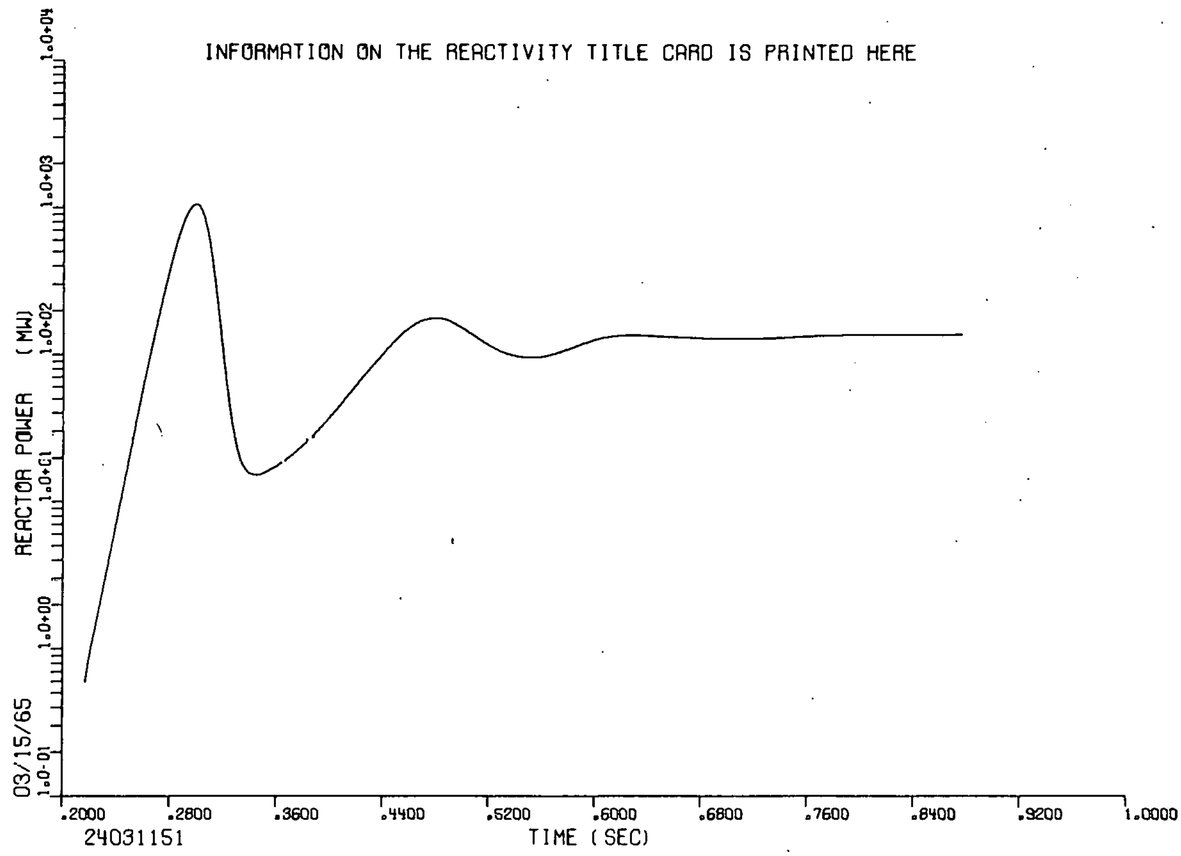

Fig. 15 Plot of power data as prepared by the REACTIVITY program.

```
SPORT  03/15/65                              SAMPLE OUTPUT FROM THE SPORT PROGRAM
-------------------------------------------------------------------------------------------------------------
REACTIVITY PROGRAM                                                        DG P L I PRE S
                                                                          ER C I N WTN C
                                                                          LO   S T     A
-------------------------------------------------------------------------------------------------------------
        INFORMATION ON THE REACTIVITY TITLE CARD IS PRIBTED HERE          AU C T   PPP L
                                                                          YP O N E LLL E
                     LAMBDA / BETA BAR        INITIAL AVERAGE RECIPR. PERIOD  PS N G N TTT S  INITIAL ENERGY     SOURCE
-------------------------------------------------------------------------------------------------------------
CONTROL CARD WAS-        0.00300000              104.00000000              6 0 0 0 121 00    -0.                -0.
-------------------------------------------------------------------------------------------------------------
                                                  LAMBDA'S
   0.012700000   0.031700000   0.116000000   0.311000001   1.400000006   3.870000005
-------------------------------------------------------------------------------------------------------------
                                                    F'S
-------------------------------------------------------------------------------------------------------------
   0.038000000   0.213000000   0.187999999   0.407000002   0.128000000   0.026000000
-------------------------------------------------------------------------------------------------------------
```

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
24031151	0.217300	0.6067	1.3078745	0.	0.005834	0.
24031151	0.218300	0.7118	1.3071824	-0.0006921	0.006510	-0.106304343
24031151	0.219300	0.8098	1.3086649	0.0007904	0.007280	0.108572101
24031151	0.220300	0.9127	1.3091228	0.0012483	0.008146	0.153233303
24031151	0.221300	1.0241	1.3087236	0.0008491	0.009119	0.093118912
24031151	0.222300	1.1236	1.3044104	-0.0034641	0.010186	-0.340075195
24031151	0.223300	1.2516	1.3046512	-0.0032234	0.011376	-0.283356536
24031151	0.224300	1.3697	1.2994919	-0.0083826	0.012678	-0.661168493
24031151	0.225300	1.5106	1.2984872	-0.0093873	0.014116	-0.665033519
24031151	0.226300	1.6733	1.3001074	-0.0077672	0.015707	-0.494505748
24031151	0.227300	1.8725	1.3068947	-0.0009798	0.017486	-0.056035528
24031151	0.228300	2.0679	1.3052120	-0.0026625	0.019450	-0.136886811
24031151	0.229300	2.2896	1.3048679	-0.0030066	0.021626	-0.139027270
24031151	0.230300	2.5333	1.3043095	-0.0035650	0.024034	-0.148332996
24031151	0.231300	2.8006	1.3035385	-0.0043361	0.026696	-0.162425866
24031151	0.232300	3.0998	1.3036218	-0.0042527	0.029642	-0.143469768
24031151	0.233300	3.4307	1.3037254	-0.0041491	0.032903	-0.126100987
24031151	0.234300	3.8014	1.3042823	-0.0035922	0.036516	-0.098373856
24031151	0.235300	4.2140	1.3049667	-0.0029078	0.040521	-0.071761592
24031151	0.236300	4.6774	1.3058175	-0.0020570	0.044965	-0.045747375
24031151	0.237300	5.1962	1.3067300	-0.0011445	0.049901	-0.022934882
24031151	0.238300	5.7676	1.3074216	-0.0004529	0.055380	-0.008177867
24031151	0.239300	6.4041	1.3082035	0.0003290	0.061462	0.005353150
24031151	0.240300	7.1144	1.3090468	0.0011723	0.068218	0.017184582
24031151	0.241300	7.8985	1.3094488	0.0015743	0.075718	0.020791612
24031151	0.242300	8.7668	1.3100271	0.0021526	0.084042	0.025613395
24031151	0.243300	9.7269	1.3104514	0.0025769	0.093277	0.027626310
24031151	0.244300	10.7911	1.3108792	0.0030047	0.103522	0.029024948
24031151	0.245300	11.9715	1.3112463	0.0033718	0.114887	0.029348587
24031151	0.246300	13.2798	1.3115610	0.0036865	0.127493	0.028915305
24031151	0.247300	14.7461	1.3123405	0.0044660	0.141490	0.031564058
24031151	0.248300	16.3971	1.3133190	0.0054445	0.157051	0.034666803
24031151	0.249300	18.2464	1.3142251	0.0063506	0.174365	0.036421101
24031151	0.250300	20.3078	1.3147410	0.0068665	0.193633	0.035461315
24031151	0.251300	22.6122	1.3150213	0.0071468	0.215086	0.033227668
24031151	0.252300	25.1821	1.3151084	0.0072338	0.238976	0.030270142
24031151	0.253300	28.0484	1.3149998	0.0071252	0.265585	0.026828478
24031151	0.254300	31.2454	1.3146234	0.0067489	0.295229	0.022859966
24031151	0.255300	34.8024	1.3138220	0.0059475	0.328250	0.018118859
24031151	0.256300	38.7586	1.3126440	0.0047695	0.365031	0.013066015
24031151	0.257300	43.1288	1.3108804	0.0030059	0.405971	0.007404138
24031151	0.258300	47.9356	1.3086894	0.0008149	0.451488	0.001804854
24031151	0.259300	53.2481	1.3063294	-0.0015451	0.502069	-0.003077530
24031151	0.260300	59.1011	1.3035228	-0.0043518	0.558233	-0.007795628
24031151	0.261300	65.4979	1.3004819	-0.0073926	0.620507	-0.011913825
24031151	0.262300	72.4660	1.2973678	-0.0105068	0.689441	-0.015239540
24031151	0.263300	80.0752	1.2944105	-0.0134640	0.765650	-0.017585065
24031151	0.264300	88.3899	1.2913908	-0.0164837	0.849813	-0.019396873
24031151	0.265300	97.4319	1.2885984	-0.0192762	0.942630	-0.020449343
24031151	0.266300	107.2775	1.2859261	-0.0219485	1.044871	-0.021005922

SPORT 03/15/65 SAMPLE OUTPUT FROM THE SPORT PROGRAM PAGE 32

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
24031151	0.867300	138.0873	0.8067284	-0.5011461	91.780723	-0.005460254
24031151	0.868300	138.1828	0.8069343	-0.5009403	91.918892	-0.005449807
24031151	0.869300	138.3477	0.8075962	-0.5002783	92.057210	-0.005434429
24031151	0.870300	138.3730	0.8073696	-0.5005049	92.195555	-0.005428731
24031151	0.871300	138.4623	0.8075639	-0.5003106	92.333982	-0.005418488
24031151	0.872300	138.4226	0.8068203	-0.5010543	92.472382	-0.005418421
24031151	0.873300	138.4395	0.8065032	-0.5013713	92.610801	-0.005413746
24031151	0.874300	138.5246	0.8067039	-0.5011706	92.749298	-0.005403498
24031151	0.875300	138.5774	0.8065280	-0.5013465	92.887849	-0.005397331
24031151	0.876300	138.6285	0.8063499	-0.5015246	93.026451	-0.005391204

CALCULATIONS REQUIRED 0 MIN 34.9 SEC AND PLOT(S) REQUIRED 0 MIN 44.3 SEC

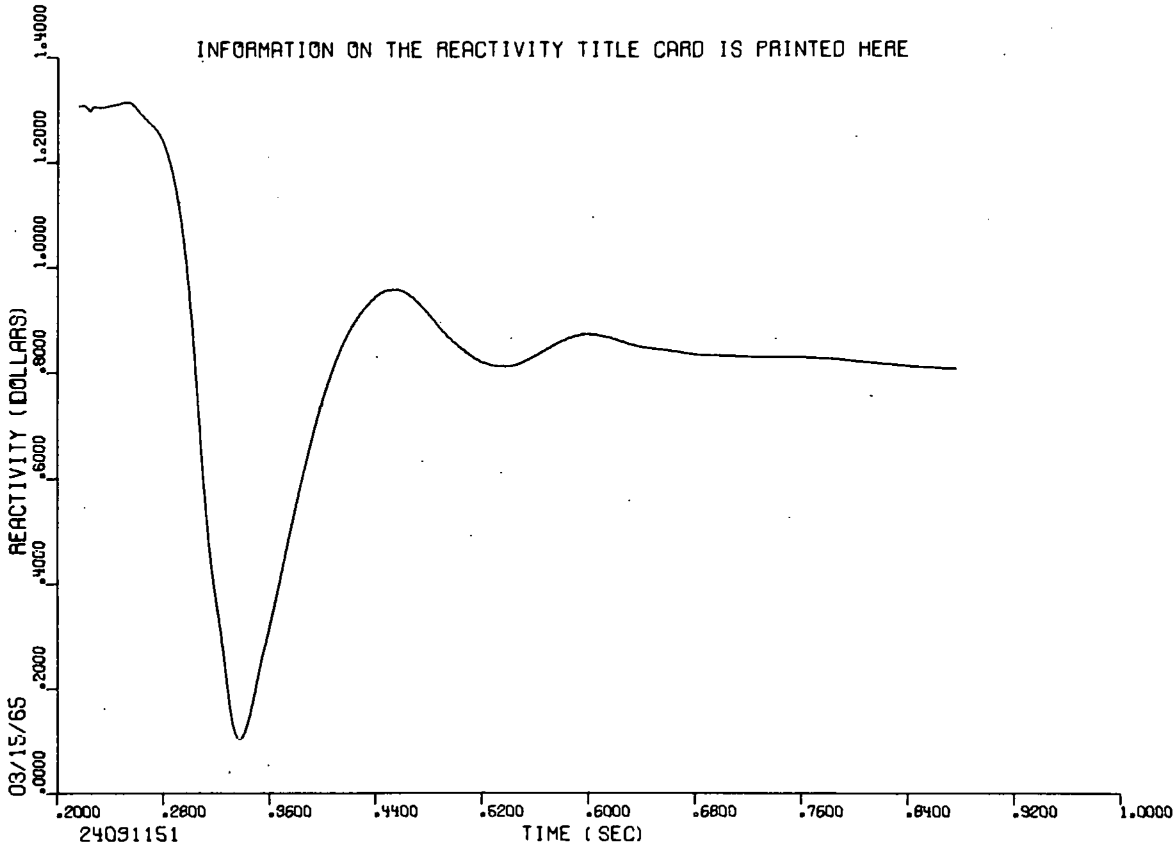

Fig. 16 Plot of reactivity as prepared by the REACTIVITY program.

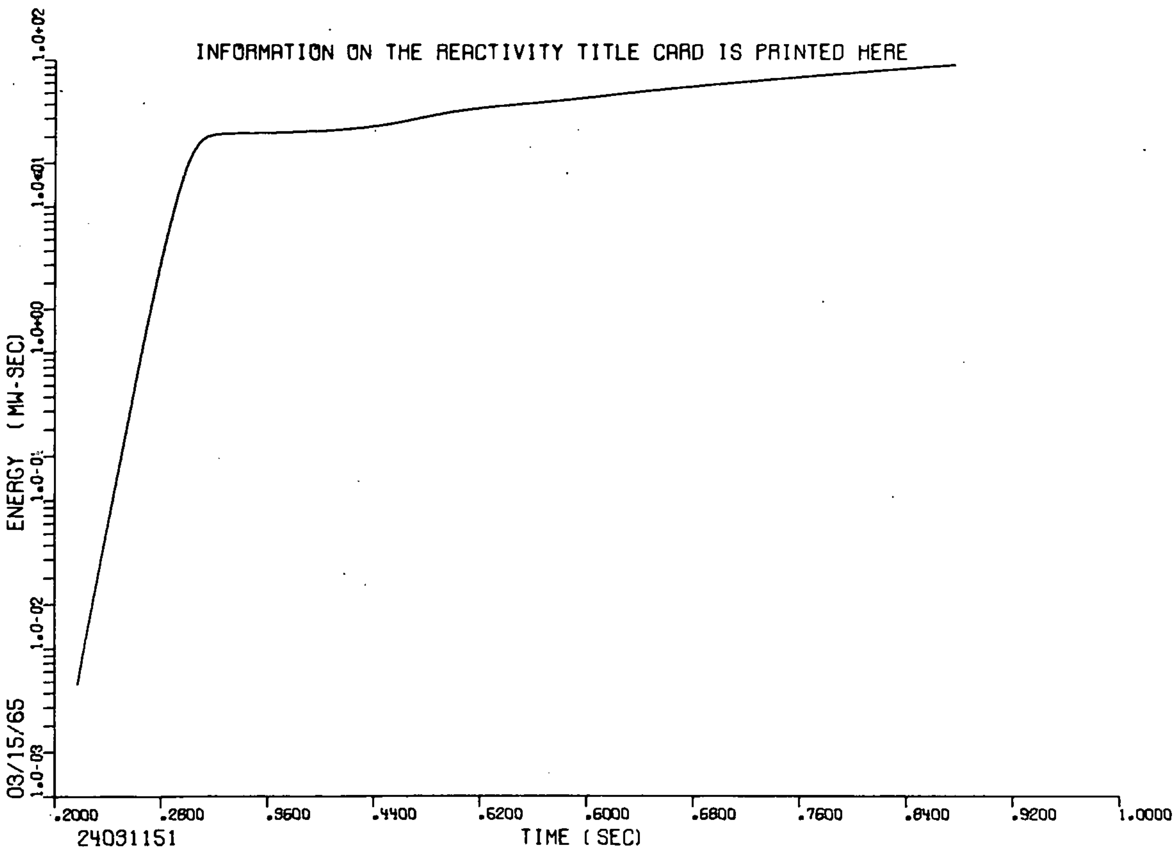

Fig. 17 Plot of energy as prepared by the REACTIVITY program.

5. FREQUENCY RESPONSE PROGRAM OUTPUT

The values on the FREQUENCY RESPONSE CONTROL Card are listed on the first page in the FREQUENCY RESPONSE program output in the same order in which they were entered (page 71). The OMEGA cards are listed next. Page 72 is an example of the FREQUENCY RESPONSE output listing. The identification number, frequency, and the real part, imaginary part, phase in degrees, and decibel magnitude of the FREQUENCY RESPONSE output may be punched on cards in the format:

(I10, F14.4, 2E14.7, F14.8, F14.7) .

Figures 18 and 19 are examples of FREQUENCY RESPONSE output plots.

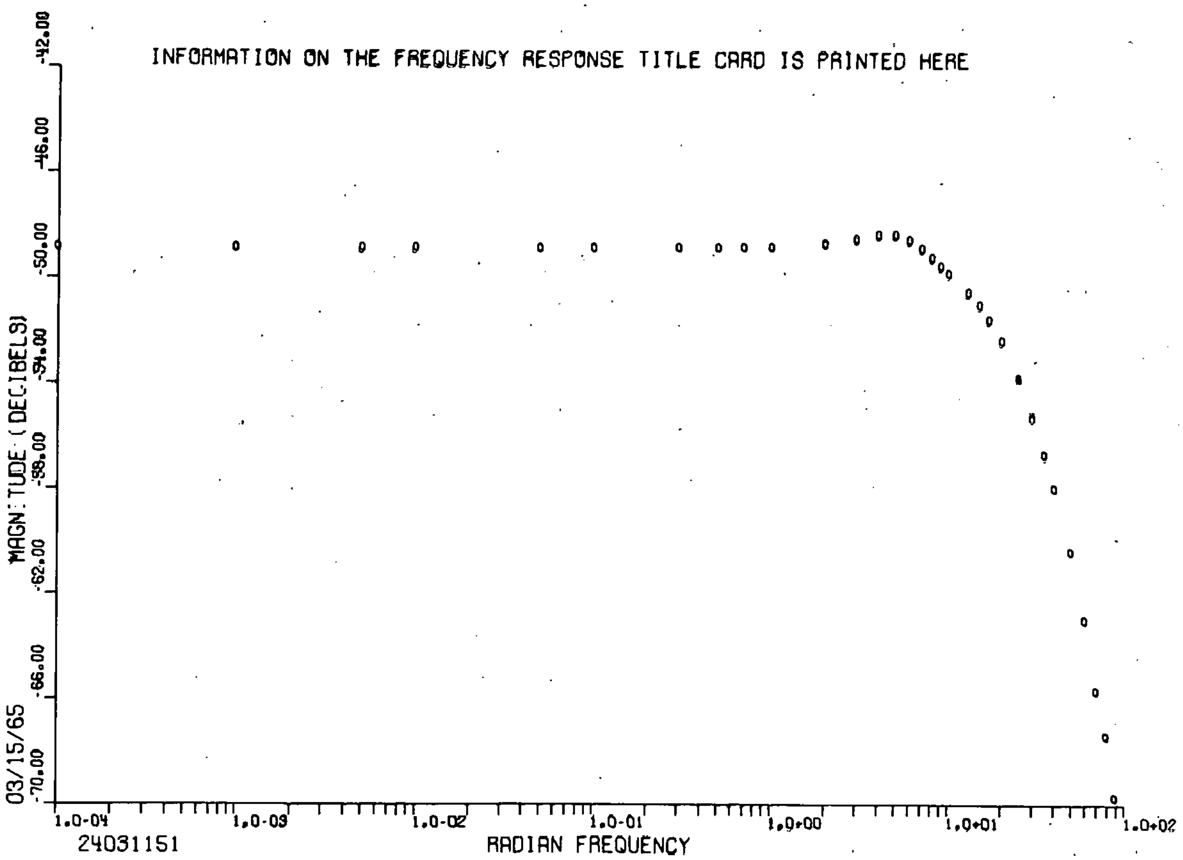

Fig. 18 Plot of the magnitude of the transformation calculated (and plotted) by FREQUENCY RESPONSE.

FREQUENCY RESPONSE PROGRAM

INFORMATION ON THE FREQUENCY RESPONSE TITLE CARD IS PRINTED HERE

CONTROL CARD WAS- 32 311 2 0 0 ALPHA = -0.

RADIAN FREQUENCIES

0.0001000	0.0010000	0.0050000	0.0100000	0.0500000	0.1000000	0.3000000	0.5000000
0.7000000	1.0000000	2.0000000	3.0000000	4.0000000	5.0000000	6.0000000	7.0000000
8.0000000	9.0000000	10.0000000	13.0000000	15.0000000	17.0000000	20.0000000	25.0000000
30.0000000	35.0000000	40.0000000	50.0000000	60.0000000	70.0000000	80.0000000	90.0000000

SPORT 03/15/65 SAMPLE OUTPUT FROM THE SPORT PROGRAM

RECORD NO 24031151 CHANNEL 0 NUMERATOR WAS WORD 3, DENOMINATOR WAS WORD 1

FREQUENCY	LOG W	REAL G(IW)	IMAG. G(IW)	MAG. G	PHASE ANGLE	20 LOG(MAG. G)
0.0001	-4.000	-3.6177646E-03	1.7699922E-08	3.6177646E-03	-180.00027847	-48.8311939
0.0010	-3.000	-3.6177646E-03	1.7699933E-07	3.6177646E-03	-180.00279999	-48.8311939
0.0050	-2.301	-3.6177632E-03	8.8499522E-07	3.6177633E-03	-180.01401520	-48.8311973
0.0100	-2.000	-3.6177646E-03	1.7699877E-06	3.6177650E-03	-180.02803040	-48.8311934
0.0500	-1.301	-3.6178045E-03	8.8504316E-06	3.6178153E-03	-180.14016342	-48.8310728
0.1000	-1.000	-3.6179305E-03	1.7704835E-05	3.6179739E-03	-180.28038025	-48.8306913
0.3000	-0.523	-3.6192648E-03	5.3233030E-05	3.6196562E-03	-180.84265709	-48.8266540
0.5000	-0.301	-3.6219167E-03	8.9117620E-05	3.6230129E-03	-181.40948105	-48.8186026
0.7000	-0.155	-3.6258499E-03	1.2559846E-04	3.6280246E-03	-181.98391342	-48.8065958
1.0000	0.	-3.6340241E-03	1.8197164E-04	3.6385773E-03	-182.86665726	-48.7813687
2.0000	0.301	-3.6763129E-03	3.9439289E-04	3.6974075E-03	-186.12323952	-48.6420541
3.0000	0.477	-3.7190838E-03	6.6696938E-04	3.7784167E-03	-190.16717339	-48.4538035
4.0000	0.602	-3.7088761E-03	1.0101001E-03	3.8439646E-03	-195.23481750	-48.3044124
5.0000	0.699	-3.5873769E-03	1.3802759E-03	3.8437527E-03	-201.04468346	-48.3048921
6.0000	0.778	-3.3558752E-03	1.6932368E-03	3.7588494E-03	-206.77363396	-48.4989014
7.0000	0.845	-3.0813802E-03	1.9052667E-03	3.6228365E-03	-211.72916222	-48.8190260
8.0000	0.903	-2.8223450E-03	2.0375660E-03	3.4809921E-03	-215.82705116	-49.1659393
9.0000	0.954	-2.5951356E-03	2.1281088E-03	3.3561251E-03	-219.35303879	-49.4832377
10.0000	1.000	-2.3926430E-03	2.2009502E-03	3.2509879E-03	-222.61040306	-49.7596936
13.0000	1.114	-1.8359321E-03	2.3668752E-03	2.9954540E-03	-232.20006371	-50.4707470
15.0000	1.176	-1.4750904E-03	2.4130323E-03	2.8281825E-03	-238.56248474	-50.9698515
17.0000	1.230	-1.1420761E-03	2.3988066E-03	2.6568046E-03	-244.54079437	-51.5128078
20.0000	1.301	-7.1790998E-04	2.3099813E-03	2.4189684E-03	-252.73547935	-52.3273969
25.0000	1.398	-1.5856793E-04	2.0515625E-03	2.0576813E-03	-265.58031845	-53.7324386
30.0000	1.477	1.8235952E-04	1.7148876E-03	1.7245563E-03	-276.06996536	-55.2664523
35.0000	1.544	3.7551903E-04	1.4235724E-03	1.4722679E-03	-284.77723694	-56.6402636
40.0000	1.602	4.8770136E-04	1.1720293E-03	1.2694508E-03	-292.59302521	-57.9276829
50.0000	1.699	6.0532038E-04	7.4749436E-04	9.6185267E-04	-309.00052643	-60.3378296
60.0000	1.778	5.4954005E-04	4.5451175E-04	7.1314458E-04	-320.40664291	-62.9364491
70.0000	1.845	4.5704383E-04	2.5425516E-04	5.2300548E-04	-330.91265106	-65.6298752
80.0000	1.903	3.9681780E-04	1.6368226E-04	4.2925079E-04	-337.58447647	-67.3457785
90.0000	1.954	3.2480752E-04	3.8100442E-05	3.2703450E-04	-353.30968475	-69.7081289

CALCULATIONS REQUIRED 1 MIN 4.1 SEC AND PLOT(S) REQUIRED 0 MIN 22.4 SEC

TOTAL PROBLEM TIME WAS 4 MIN 60.0 SEC

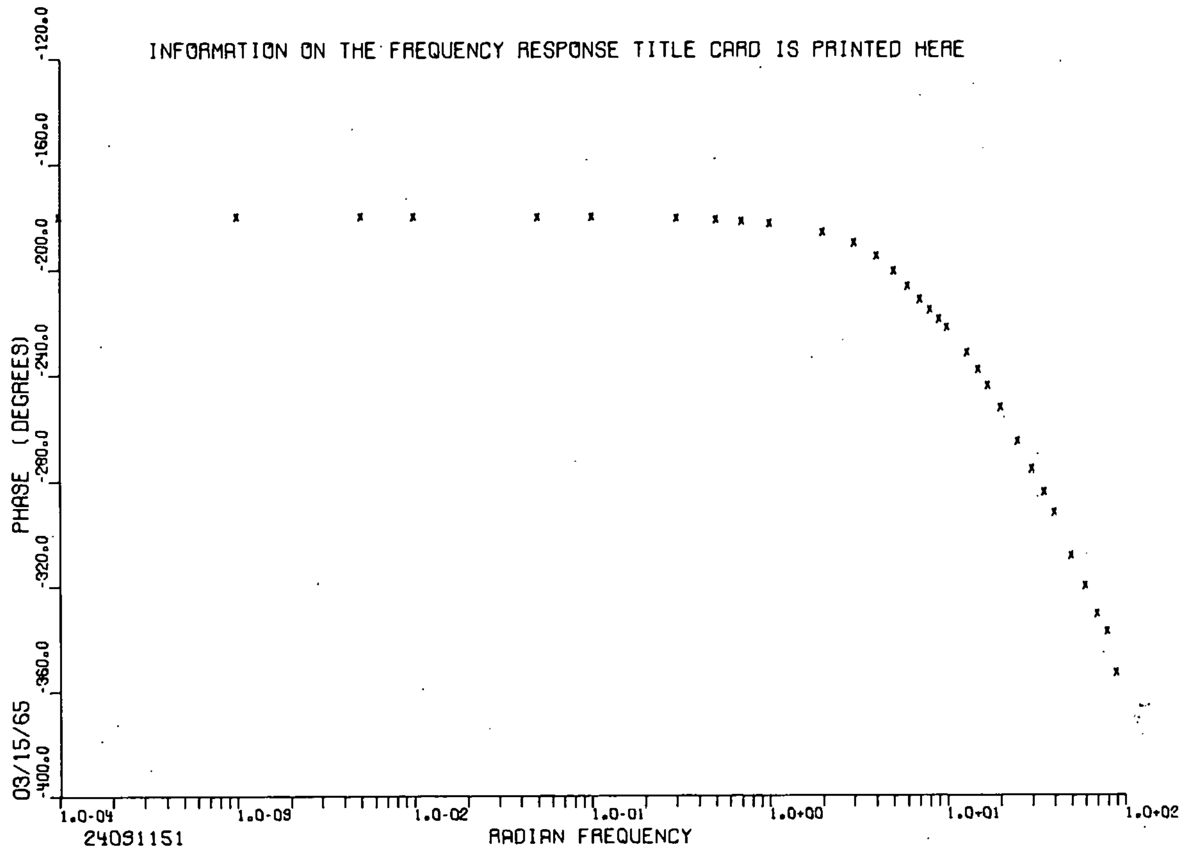

Fig. 19 Plot of the phase of the transformation calculated (and plotted) by FREQUENCY RESPONSE.

V. SAMPLE PROBLEMS

This section is presented in two parts: (a) an example of one of the most typical SPORT processing applications and (b) sample sets of control cards that might be used for other common processing schemes.

1. TYPICAL PROBLEM

On the following pages, the input control cards and the resulting output for a typical SPORT problem are listed. In this problem, SPORT assembles a composite power channel from three "saturating" channels and one "peaking" channel of Spert I power data recorded during the destructive test in October, 1962. The composite power is plotted and then smoothed three times in preparation for the REACTIVITY program calculations which complete the problem. Plots of coefficients C and B in the SMOOTH program output and of the reactivity in the REACTIVITY program output are generated. The output listings from the SMOOTH and REACTIVITY programs are suppressed for the sake of brevity.

```
                 INPUT CONTROL CARDS  SPERT I DESTRUCTIVE TEST           PAGE  1

00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

205 -60101                 SPERT I DESTRUCTIVE TEST  10/26/62
0040541104 0.098000  0.103220            1.170550                    0932
0040541103           0.109250
0040541102           0.116000
0040541101           0.131300
0040541102           0.136250
0040541103           0.138880            1.059840
                      SPERT I DESTRUCTIVE TEST  10/26/62
0040541000 0.000030                                         63330003
                      SPERT I DESTRUCTIVE TEST  10/26/62
 0.008160   312.5   0603002000
  0.0127    0.0317    0.116     0.311     1.40      3.87    'LAMBDA' CARD
  0.038     0.213     0.188     0.407     0.128     0.026     'F' CARD
*STOP
```

PART CARD WAS 205 -60101 SPERT I DESTRUCTIVE TEST OCTOBER 26, 1962

REEL NUMBER 932

CHANNEL ID NO	FILE NO (IF ANY)	MINIMUM TIME	MAXIMUM TIME	NORMALIZING COEFFICIENTS TIME	NORMALIZING COEFFICIENTS DATA	TIME SHIFT	DATA SHIFT
40541104	-0	0.098000	0.103220	1.000000	1.1705500E 00	-0.	-0.
40541103	-0	0.103220	0.109250	1.000000	1.0000000E 00	-0.	-0.
40541102	-0	0.109250	0.116000	1.000000	1.0000000E 00	-0.	-0.
40541101	-0	0.116000	0.131300	1.000000	1.0000000E 00	-0.	-0.
40541102	-0	0.131300	0.136250	1.000000	1.0000000E 00	-0.	-0.
40541103	-0	0.136250	0.138880	1.000000	1.0598400E 00	-0.	-0.

DATA TAPE MOUNTING TIME - 0 MIN 2.3 SEC

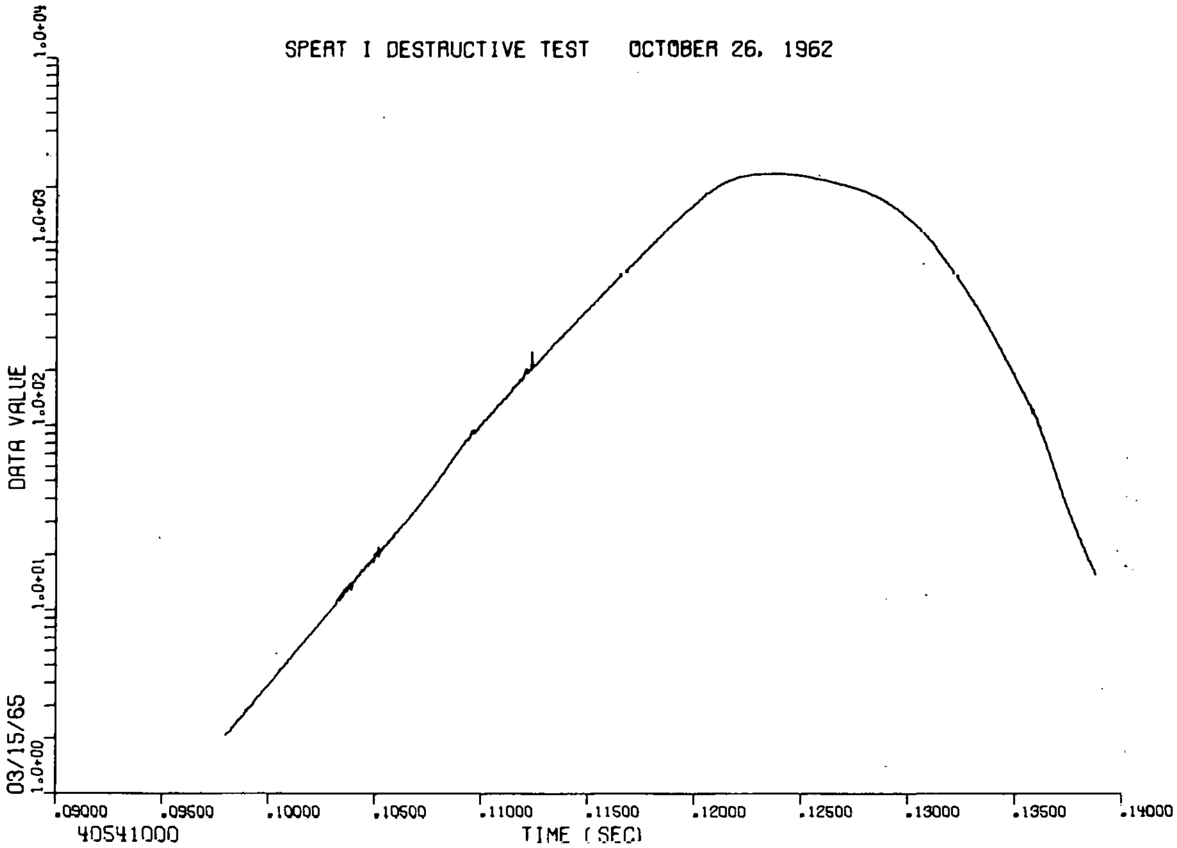

Fig. 20 Sample plot of power data as prepared in the data preparation phase of SPORT.

DATA PREPARATION REQUIRED 0 MIN 39.1 SEC AND DATA PLOT REQUIRED 0 MIN 14.0 SEC

SPORT 03/15/65 SPERT I DESTRUCTIVE TEST OCTOBER 26, 1962

QUADRATIC SMOOTHING PROGRAM

SPERT I DESTRUCTIVE TEST OCTOBER 26, 1962

PASS NUMBER 1	ID NO	DELTA T	T MINIMUM	T MAXIMUM	T START CAL	1ST OUTPUT T	N L S O R TD U I PDC R E RS M S LAA D C AM B T OTL E Y NN R G TAE R L ST
SMOOTH CONTROL CARD WAS-	40541000	0.000030	-0.	-0.	-0.	-0.	63 3 300 0 3-00
CONTROL WORDS RESET -					0.098960	0.098960	

CALCULATIONS REQUIRED 0 MIN 54.5 SEC

BEGIN PASS 2		
CONTROL WORDS RESET -	0.098960	0.098960

CALCULATIONS REQUIRED 1 MIN 4.1 SEC

BEGIN PASS 3		
CONTROL WORDS RESET -	0.098960	0.098960

CALCULATIONS REQUIRED 1 MIN 4.7 SEC AND PLOT REQUIRED 0 MIN 34.4 SEC

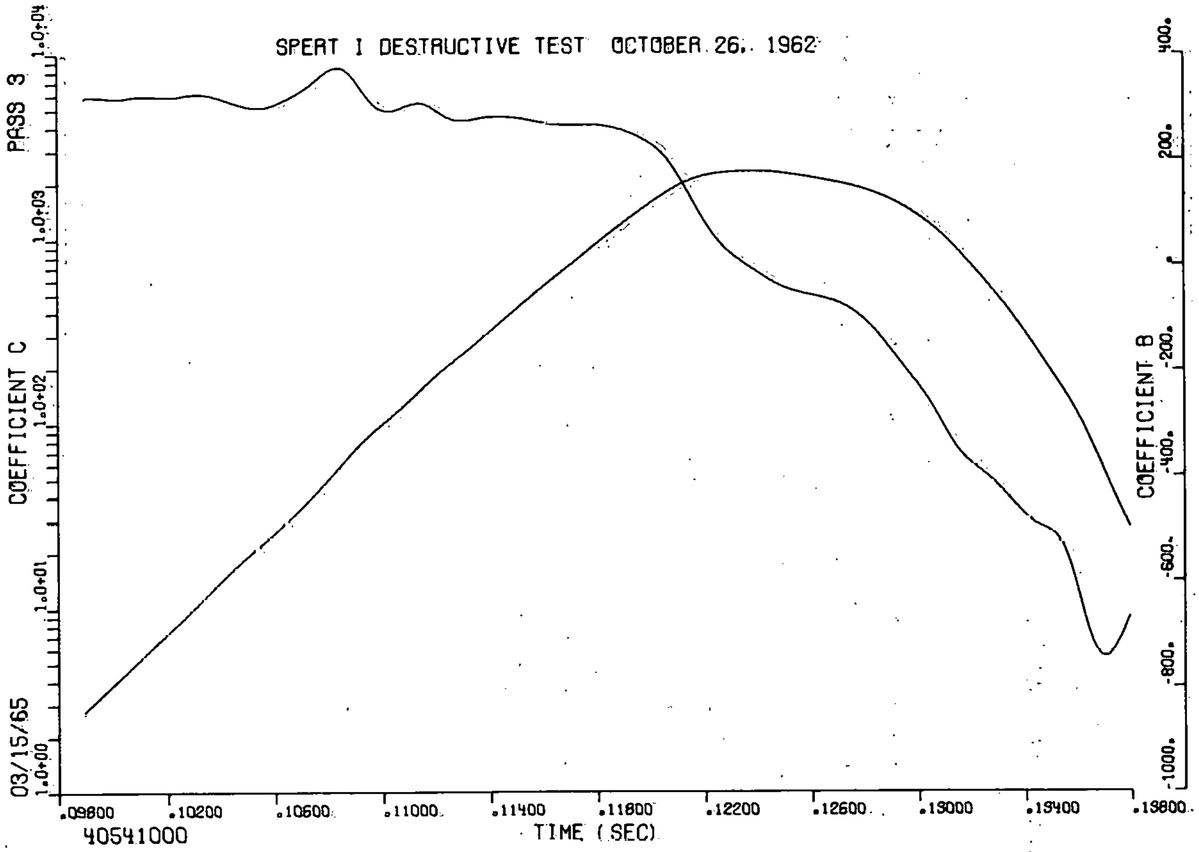

Fig. 21 Sample plot of power data and slope as prepared by SMOOTH.

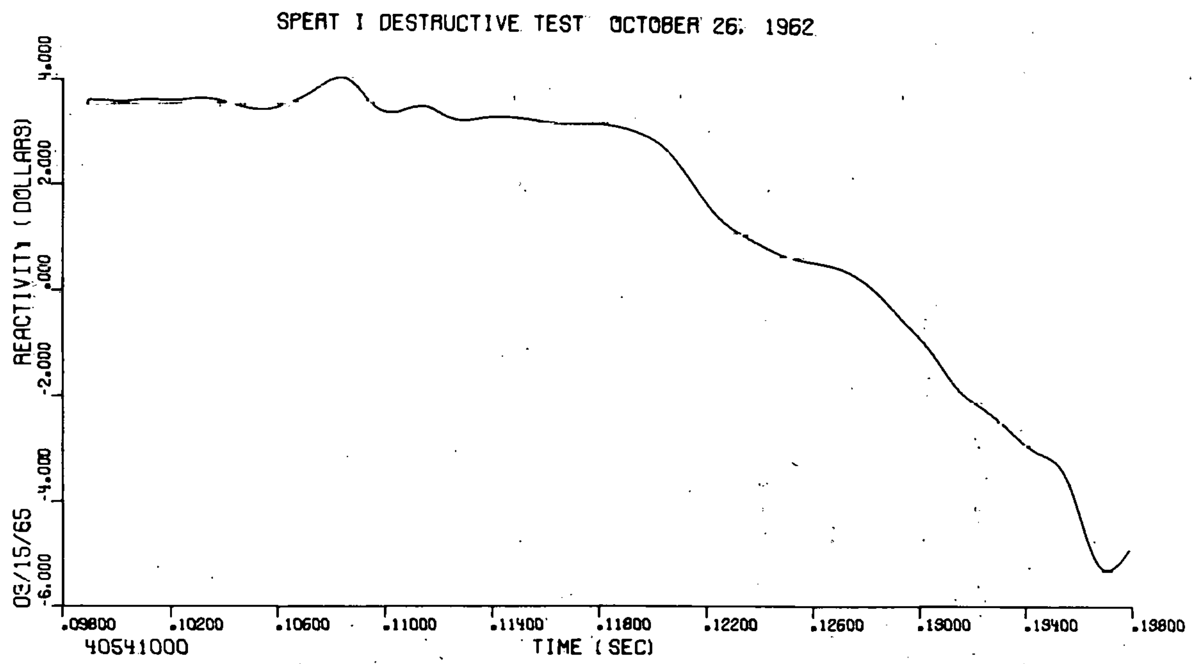

Fig. 22 Sample plot of calculated reactivity as prepared by the REACTIVITY program.

REACTIVITY PROGRAM

```
                                                                     DG P L I PRE S
                                                                     ER C I N WTN C
                                                                     LO   S T     A
            SPERT I DESTRUCTIVE TEST  OCTOBER 26, 1962               AU C T   PPP L
                                                                     YP O N E LLL E
                  LAMBDA / BETA BAR      INITIAL AVERAGE RECIPR. PERIOD  PS N G N TTT S  INITIAL ENERGY    SOURCE

CONTROL CARD WAS-    0.00816000              312.50000000             6 0 3 0 020 00    -0.              -0.
```

LAMBDA'S

0.012700000	0.031700000	0.116000000	0.311000001	1.400000006	3.870000005

F'S

0.038000000	0.213000000	0.187999999	0.407000002	0.128000000	0.026000000

CALCULATIONS REQUIRED 0 MIN 28.9 SEC AND PLOT(S) REQUIRED 0 MIN 19.1 SEC

TOTAL PROBLEM TIME WAS 5 MIN 19.4 SEC

2. SAMPLE SETS OF CONTROL CARDS FOR COMMON APPLICATIONS

On the following pages, a number of sets of SPORT control cards are listed. A brief description of the significance of each set is included below.

Example 1. Example 1 illustrates the SPORT control cards necessary to prepare and plot a section of Type 5 data from data Channel 0240602108 stored on Computing Center Reel Number 596.

Example 2. Example 2 illustrates the SPORT control cards necessary to prepare and plot a section of Type 1 data from Channel 6 in the deck of Spert 1 through 3 data cards included in the input card deck.

Example 3. Example 3 illustrates the SPORT control cards necessary to prepare, plot, and repunch a composite power channel from 7 sections of Channels 3, 5, and 6 in the deck of Spert 1-3 data cards included in the control card sequence.

Example 4. Example 4 illustrates the SPORT control cards necessary to prepare and plot all the data from Channel 1 in the deck of 650 floating-point data cards included in the control card sequence and to process the prepared data with the SMOOTH, REACTIVITY, and FREQUENCY RESPONSE programs.

Example 5. Example 5 illustrates the SPORT control cards necessary to prepare and smooth two channels of data stored on the same reel of magnetic tape with the primary purpose of obtaining decks of smoothed even time increment card data for use in another program. Since the Computing Center Reel Number is not specified in this case, the machine operator must be told where to locate the data.

Example 6. Example 6 illustrates the SPORT control cards necessary to prepare and smooth Channels 3, 5, and 6 in the deck of Spert 1-3 data cards included in the control card sequence.

Example 7. Example 7 illustrates the SPORT control cards necessary to prepare and smooth 3 channels of Type 5 data stored on Computing Center Reel Number 910 with the primary purpose of obtaining plots which can be used to estimate where the three data channels could best be joined together to form a single composite data channel.

Example 8. Example 8 illustrates the SPORT control cards necessary to assemble sections of data from two channels stored on Computing Center Reel Number 166 into a single composite channel while suppressing all data in a "bad" section near the center of the two channels.

Example 9. Example 9 illustrates the SPORT control cards necessary to process a channel of data in a deck of Type 4 data cards (included in the control card sequence) directly with the FREQUENCY RESPONSE PROGRAM.

Example 10. Example 10 illustrates the SPORT control cards necessary to process a channel of Type 5 reactor noise data directly with the FREQUENCY RESPONSE program. The composite data channel assembled by SPORT has the last data value set equal to zero.

Example 11. Example 11 illustrates the SPORT control cards necessary to prepare and smooth two channels of Type 5 data stored on Computing Center Reel 113 and then process the two smoothed channels with the FREQUENCY RESPONSE program. Notice that two separate problems are used.

SAMPLE SETS OF CONTROL CARDS FOR COMMON APPLICATIONS   PAGE 1

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

005 +11101          EXAMPLE  1                   *SPORT PROCESSING SYSTEM*
0240602108             10.0                                              596
*STOP

001 +11101          EXAMPLE  2                   *SPORT PROCESSING SYSTEM*
         6  0.0        1.000      0.0001     10.0
********************************* DATA CARD DECK ********************************
                               (BLANK END-OF-DATA CARD)
*STOP

001 -72101          EXAMPLE  3                   *SPORT PROCESSING SYSTEM*
         3              0.255      0.0001     0.1
         5              0.280      0.0001
         6              0.313      0.0001     10.0
         5              0.333      0.0001
         3              0.399      0.0001     0.1
         5              1.023      0.0001
         3                         0.0001     0.1
********************************* DATA CARD DECK ********************************
                               (BLANK END-OF-DATA CARD)
*STOP

212 +11001          EXAMPLE  4                   *SPORT PROCESSING SYSTEM*
         1
********************************* DATA CARD DECK ********************************
                               (BLANK END-OF-DATA CARD)
         SMOOTH TITLE CARD                       *SPORT PROCESSING SYSTEM*
0024035661  0.002    0.275                      0.303              21 3
         REACTIVITY TITLE CARD                   *SPORT PROCESSING SYSTEM*
  0.003     92.6     6    11
  0.0127    0.0317   0.116     0.311     1.40      3.87     'LAMBDA' CARD
  0.038     0.213    0.188     0.407     0.128     0.026     'F' CARD
         FREQUENCY RESPONSE TITLE CARD           *SPORT PROCESSING SYSTEM*
008311
  0.0001    0.001    0.005     0.01     0.05        0.10      0.3       0.5
*STOP

105 +21000          EXAMPLE  5                   *SPORT PROCESSING SYSTEM*
 240602209
 240602210
         SMOOTH TITLE CARD                       *SPORT PROCESSING SYSTEM*
 240602209  0.0085                            6.102    6.102      251
         SMOOTH TITLE CARD                       *SPORT PROCESSING SYSTEM*
 240602210  0.0085                            6.102    6.102      251
*STOP
```

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

101 +31101         EXAMPLE  6               *SPORT PROCESSING SYSTEM*
        3                       0.0001    0.1
        5                       0.0001
        6                       0.0001    10.0
******************************** DATA CARD DECK ********************************
                            (BLANK END-OF-DATA CARD)
         SMOOTH TITLE CARD                  *SPORT PROCESSING SYSTEM*
0024031151  0.001                                       21 3   2
         SMOOTH TITLE CARD                  *SPORT PROCESSING SYSTEM*
0024031151  0.001                                       21 3   2
         SMOOTH TITLE CARD                  *SPORT PROCESSING SYSTEM*
0024031151  0.001                                       21 3   2
*STOP

105 +31101         EXAMPLE  7               *SPORT PROCESSING SYSTEM*
0210542106  0.0      2.00                 0.852                            910
0210542107  0.0      2.00
0210542108  0.0      2.0000
         SMOOTH TITLE CARD                  *SPORT PROCESSING SYSTEM*
0210542106  0.001                                       25 3 1 3
  0.500     2.000     -2.0      +3.0      -5.0      15.0    1510
         SMOOTH TITLE CARD                  *SPORT PROCESSING SYSTEM*
0210542107  0.001                                       25 3 1 3
  0.500     2.000     -2.0      +3.0      -5.0      15.0    1510
         SMOOTH TITLE CARD                  *SPORT PROCESSING SYSTEM*
0210542108  0.001                                       25 3 1 3
  0.500     2.000     -2.0      +3.0      -5.0      15.0    1510
*STOP

205 -31101         EXAMPLE  8               *SPORT PROCESSING SYSTEM*
0240602106           6.99025            0.88540683                         166
0240602107           7.16535            1.11291271 100000.0
0240602108
         SMOOTH TITLE CARD                  *SPORT PROCESSING SYSTEM*
0240602678  0.0085                                      25 3 1 2
  6.0       9.0       -1.0      +2.0      -3.0      +7.0    1510
         REACTIVITY TITLE CARD              *SPORT PROCESSING SYSTEM*
 0.064      0.0     15   0101
                          6.0  9.0  0.3  1.3 1510
0.0127    0.0317    0.115     0.311     1.4       3.87      0.277     0.0169
0.00481   0.0015    0.000428  0.000117  .0000437  .00000363 .000000624
 0.0329   0.185     0.163     0.353     0.110     0.0223    0.0865    0.027
 0.00932  0.00447   0.00275   0.00312   0.000433  0.000139  .000068
*STOP
```

SAMPLE SETS OF CONTROL CARDS FOR COMMON APPLICATIONS PAGE 3

```
00000000011111111112222222222333333333344444444445555555555666666666677777777778
12345678901234567890123456789012345678901234567890123456789012345678901234567890

514   1               EXAMPLE  9                 *SPORT PROCESSING SYSTEM*
3333333333  0.005
4      (I10,5E14.8)
******************************** DATA CARD DECK ********************************
                              (BLANK END-OF-DATA CARD)
       FREQUENCY RESPONSE TITLE CARD         *SPORT PROCESSING SYSTEM*
 811121                 12.0
  0.01       0.012      0.014      0.016      0.018      0.02       0.023      0.026
  0.03       0.035      0.04       0.05       0.06       0.07       0.08       0.09
  0.1        0.12       0.14       0.16       0.18       0.2        0.23       0.26
  0.30       0.35       0.4        0.5        0.6        0.7        0.8        0.9
  1.0        1.2        1.4        1.6        1.8        2.0        2.3        2.6
  3.0        3.5        4.0        5.0        6.0        7.0        8.0        9.0
  10.0       12.0       14.0       16.0       18.0       20.0       23.0       26.0
  30.0       35.0       40.0       50.0       60.0       70.0       80.0       90.0
  100.0      120.0      140.0      160.0      180.0      200.0      230.0      260.0
  300.0      350.0      400.0      500.0      600.0      700.0      800.0      900.0
  1000.0
*STOP

515 -31002            EXAMPLE 10                 *SPORT PROCESSING SYSTEM*
0111113025                6.996780    4.0          1.0+3 -0.40                 649
0111113025                6.999300    4.0          1.0-29 -0.40
0111113025                6.999300    4.0          1.0+3 -0.40
       FREQUENCY RESPONSE TITLE CARD         *SPORT PROCESSING SYSTEM*
013102101
  4.00       5.00       6.30       8.00       10.0       12.5       16.0       20.0
  25.0       31.5       40.0       50.0       63.0
*STOP

105 +11001            EXAMPLE 11-A               *SPORT PROCESSING SYSTEM*
 150063206                                                                     113
       SMOOTH TITLE CARD                     *SPORT PROCESSING SYSTEM*
0150063206.0009          6.0891      7.2564     6.3231               81      31
*CONTINUE
315 +11001            EXAMPLE 11-B               *SPORT PROCESSING SYSTEM*
 150063207                                                                     113
       SMOOTH TITLE CARD                     *SPORT PROCESSING SYSTEM*
0150063207.0009          6.0891      7.2564     6.3231               81       3
       FREQUENCY RESPONSE TITLE CARD         *SPORT PROCESSING SYSTEM*
 481142
 0.0001     0.001      0.01       0.1        0.2        0.3        0.4        0.5
 0.6        0.7        0.8        0.9        1.0        1.5        2.0        3.0
 4.0        5.0        5.5        6.0        7.0        8.0        9.0        10.0
 12.0       15.0       17.0       20.0       21.0       22.0       23.0       24.0
 26.0       27.0       28.0       30.0       32.0       34.0       36.0       38.0
 40.0       42.0       44.0       46.0       48.0       50.0       52.0       54.0
*STOP
```

VI. CHECKOUT OF PROGRAMS

1. INTRODUCTION

In addition to functional checkout of SPORT, tests were conducted to determine if the calculations made by the programs, SMOOTH, REACTIVITY, and FREQUENCY RESPONSE, were correct within the limits of numerical evaluation. Three phases of SMOOTH were tested: (a) the effect of smoothing an increasing exponential function, (b) the effect of smoothing tape data which contains noise, and (c) the effect of resmoothing data. To determine the accuracy of the calculations made by REACTIVITY, two tests were run: (a) reactivity was calculated from power data represented by exp (αt), and (2) reactivity was calculated from power data recorded during a transient in which the reactivity was known as a function of time. The accuracy of the FREQUENCY RESPONSE program is discussed in some detail in Section II.

2. CHECKOUT OF SMOOTH

The simplest demonstration of SMOOTH is that of using as input data the function, exp (αt). If this is done and if the natural logarithm of the input data is taken, the output from SMOOTH should be a straight line with slope α. The results of such a test are shown on pages 88 through 91 where the first two and the last pages of output are given. These answers are considered to be quite adequate.

Once it has been demonstrated that the SMOOTH calculations are adequate for fictitious data, one must determine the effect of smoothing data which contains noise of relatively small magnitude. The results of such a test are presented in Figure 23. The dotted circles indicate recorded data points while the continuous curve represents output from SMOOTH.

The third test which was applied to the SMOOTH program was to determine the effectiveness of the program in removing sinusoidal noise oscillations superimposed on a function. The program was tested by generating data which contained 60-cycle noise and smoothing this data. Figures 24 through 28 demonstrate the effect of multiple smoothing both on data values and slope values.

QUADRATIC SMOOTHING PROGRAM

TEST PROBLEM TO CHECK THE ACCURACY OF SMOOTH AND REACTIVITY

PASS NUMBER 1	ID NO	DELTA T	T MINIMUM	T MAXIMUM	T START CAL	1ST OUTPUT T	NUMBR	LISTG	SPDC OLAA RTOL TAE	ORDER	RECYL	TD RS AM NN ST
SMOOTH CONTROL CARD WAS-	888888888	0.000050	-0.	-0.	-0.	-0.	25	0	000	0	0	00
CONTROL WORDS RESET	-				0.000600	0.000600						

SPORT 03/15/65 TEST PROBLEM TO CHECK THE ACCURACY OF SMOOTH AND REACTIVITY

SMOOTH PROGRAM OUTPUT LISTING FOR CHANNEL 888

ID NUMBER	TIME	C	B	A
888888888	0.000600	1.1286122	49.9999943	-0.2500000
888888888	0.000650	1.1311122	49.9999943	-0.1250000
888888888	0.000700	1.1336122	49.9999938	-0.
888888888	0.000750	1.1361122	49.9999962	-0.1250000
888888888	0.000800	1.1386122	49.9999967	-0.1250000
888888888	0.000850	1.1411122	49.9999967	-0.1250000
888888888	0.000900	1.1436122	49.9999957	-0.1250000
888888888	0.000950	1.1461122	49.9999962	-0.
888888888	0.001000	1.1486122	49.9999967	-0.1250000
888888888	0.001050	1.1511122	49.9999933	-0.
888888888	0.001100	1.1536121	49.9999938	0.2500000
888888888	0.001150	1.1561122	49.9999948	-0.
888888888	0.001200	1.1586122	49.9999943	-0.
888888888	0.001250	1.1611122	49.9999928	-0.1250000
888888888	0.001300	1.1636122	49.9999933	-0.
888888888	0.001350	1.1661122	49.9999928	-0.
888888888	0.001400	1.1686122	49.9999914	-0.
888888888	0.001450	1.1711122	49.9999900	0.1250000
888888888	0.001500	1.1736122	49.9999938	-0.1250000
888888888	0.001550	1.1761122	49.9999957	-0.
888888888	0.001600	1.1786122	49.9999943	-0.
888888888	0.001650	1.1811122	49.9999957	-0.5000000
888888888	0.001700	1.1836122	49.9999924	-0.2500000
888888888	0.001750	1.1861122	49.9999948	-0.2500000
888888888	0.001800	1.1886122	49.9999962	-0.
888888888	0.001850	1.1911122	49.9999990	-0.1250000
888888888	0.001900	1.1936122	49.9999981	-0.1250000
888888888	0.001950	1.1961122	49.9999962	-0.1250000
888888888	0.002000	1.1986122	49.9999962	-0.2500000
888888888	0.002050	1.2011122	49.9999990	-0.
888888888	0.002100	1.2036122	49.9999995	-0.2500000
888888888	0.002150	1.2061122	50.0000005	-0.2500000
888888888	0.002200	1.2086122	50.0000000	-0.
888888888	0.002250	1.2111122	49.9999990	-0.2500000
888888888	0.002300	1.2136122	49.9999990	-0.1250000
888888888	0.002350	1.2161122	50.0000010	-0.
888888888	0.002400	1.2186122	50.0000024	-0.1250000
888888888	0.002450	1.2211122	50.0000033	-0.2500000
888888888	0.002500	1.2236122	50.0000029	-0.1250000
888888888	0.002550	1.2261122	50.0000038	-0.3750000
888888888	0.002600	1.2286122	50.0000014	-0.1250000
888888888	0.002650	1.2311122	50.0000014	-0.1250000
888888888	0.002700	1.2336122	50.0000005	-0.2500000
888888888	0.002750	1.2361122	50.0000014	-0.2500000
888888888	0.002800	1.2386122	49.9999976	-0.3750000
888888888	0.002850	1.2411122	49.9999938	-0.1250000
888888888	0.002900	1.2436122	49.9999943	-0.3750000
888888888	0.002950	1.2461122	49.9999943	-0.2500000
888888888	0.003000	1.2486122	49.9999967	-0.2500000
888888888	0.003050	1.2511122	49.9999971	-0.1250000

SPORT 03/15/65 TEST PROBLEM TO CHECK THE ACCURACY OF SMOOTH AND REACTIVITY

SMOOTH PROGRAM OUTPUT LISTING FOR CHANNEL 888

ID NUMBER	TIME	C	B	A
888888888	0.003100	1.2536122	49.9999995	-0.1250000
888888888	0.003150	1.2561122	49.9999990	-0.1250000
888888888	0.003200	1.2586122	49.9999995	-0.1250000
888888888	0.003250	1.2611122	49.9999967	-0.
888888888	0.003300	1.2636122	49.9999967	-0.1250000
888888888	0.003350	1.2661122	49.9999943	-0.1250000
888888888	0.003400	1.2686122	49.9999943	-0.2500000
888888888	0.003450	1.2711122	49.9999914	-0.1250000
888888888	0.003500	1.2736122	49.9999905	-0.
888888888	0.003550	1.2761122	49.9999914	-0.
888888888	0.003600	1.2786121	49.9999938	0.1250000
888888888	0.003650	1.2811122	49.9999967	-0.
888888888	0.003700	1.2836121	49.9999976	-0.
888888888	0.003750	1.2861122	49.9999971	-0.1250000
888888888	0.003800	1.2886122	49.9999971	-0.1250000
888888888	0.003850	1.2911122	49.9999976	-0.
888888888	0.003900	1.2936121	50.0000014	0.2500000
888888888	0.003950	1.2961121	50.0000033	0.2500000
888888888	0.004000	1.2986122	50.0000043	-0.1250000
888888888	0.004050	1.3011122	50.0000014	-0.
888888888	0.004100	1.3036121	50.0000005	0.1250000
888888888	0.004150	1.3061123	50.0000010	-0.6250000
888888888	0.004200	1.3086122	50.0000038	-0.1250000
888888888	0.004250	1.3111122	50.0000057	-0.2500000
888888888	0.004300	1.3136122	50.0000067	0.1250000
888888888	0.004350	1.3161122	50.0000091	-0.2500000
888888888	0.004400	1.3186121	50.0000076	0.2500000
888888888	0.004450	1.3211122	50.0000119	-0.
888888888	0.004500	1.3236122	50.0000091	-0.1250000
888888888	0.004550	1.3261122	50.0000086	-0.1250000
888888888	0.004600	1.3286122	50.0000057	-0.2500000
888888888	0.004650	1.3311121	50.0000048	-0.
888888888	0.004700	1.3336122	50.0000005	-0.
888888888	0.004750	1.3361121	50.0000010	0.1250000
888888888	0.004800	1.3386122	49.9999971	-0.
888888888	0.004850	1.3411121	49.9999990	0.1250000
888888888	0.004900	1.3436122	49.9999962	-0.1250000
888888888	0.004950	1.3461121	49.9999957	0.3750000
888888888	0.005000	1.3486121	49.9999938	0.1250000
888888888	0.005050	1.3511122	49.9999914	-0.2500000
888888888	0.005100	1.3536122	49.9999914	-0.
888888888	0.005150	1.3561122	49.9999928	-0.
888888888	0.005200	1.3586121	49.9999938	-0.
888888888	0.005250	1.3611121	49.9999938	0.2500000
888888888	0.005300	1.3636121	49.9999957	-0.
888888888	0.005350	1.3661122	50.0000000	0.1250000
888888888	0.005400	1.3686122	49.9999995	-0.
888888888	0.005450	1.3711122	50.0000010	-0.1250000
888888888	0.005500	1.3736121	50.0000024	-0.
888888888	0.005550	1.3761121	50.0000014	0.1250000

SPORT 03/15/65 TEST PROBLEM TO CHECK THE ACCURACY OF SMOOTH AND REACTIVITY

SMOOTH PROGRAM OUTPUT LISTING FOR CHANNEL 888

ID NUMBER	TIME	C	B	A
888888888	0.118100	7.0036117	50.0000110	-2.0000000
888888888	0.118150	7.0061116	50.0000067	-0.
888888888	0.118200	7.0086117	49.9999900	-0.
888888888	0.118250	7.0111115	49.9999843	-0.
888888888	0.118300	7.0136113	49.9999671	-0.
888888888	0.118350	7.0161119	49.9999609	-3.0000000
000000000	0.110400	7.0106110	47.7777537	1.0000000
888888888	0.118450	7.0211117	49.9999452	-1.0000000
888888888	0.118500	7.0236118	49.9999480	-2.0000000
888888888	0.118550	7.0261116	49.9999385	1.0000000
888888888	0.118600	7.0286114	49.9999514	1.0000000
888888888	0.118650	7.0311115	49.9999409	-1.0000000
888888888	0.118700	7.0336118	49.9999514	-1.0000000
888888888	0.118750	7.0361116	49.9999509	-1.0000000
888888888	0.118800	7.0386117	49.9999609	-1.0000000
888888888	0.118850	7.0411116	49.9999585	-0.
888888888	0.118900	7.0436118	49.9999681	-1.0000000
888888888	0.118950	7.0461116	49.9999881	-0.
888888888	0.119000	7.0486116	49.9999967	1.0000000
888888888	0.119050	7.0511116	50.0000157	-0.
888888888	0.119100	7.0536118	50.0000229	-1.0000000
888888888	0.119150	7.0561117	50.0000415	-0.
888888888	0.119200	7.0586118	50.0000477	-1.0000000
888888888	0.119250	7.0611115	50.0000415	1.0000000
888888888	0.119300	7.0636117	50.0000448	-1.0000000
888888888	0.119350	7.0661117	50.0000358	-1.0000000
888888888	0.119400	7.0686116	50.0000367	-0.

CALCULATIONS REQUIRED 1 MIN 44.8 SEC

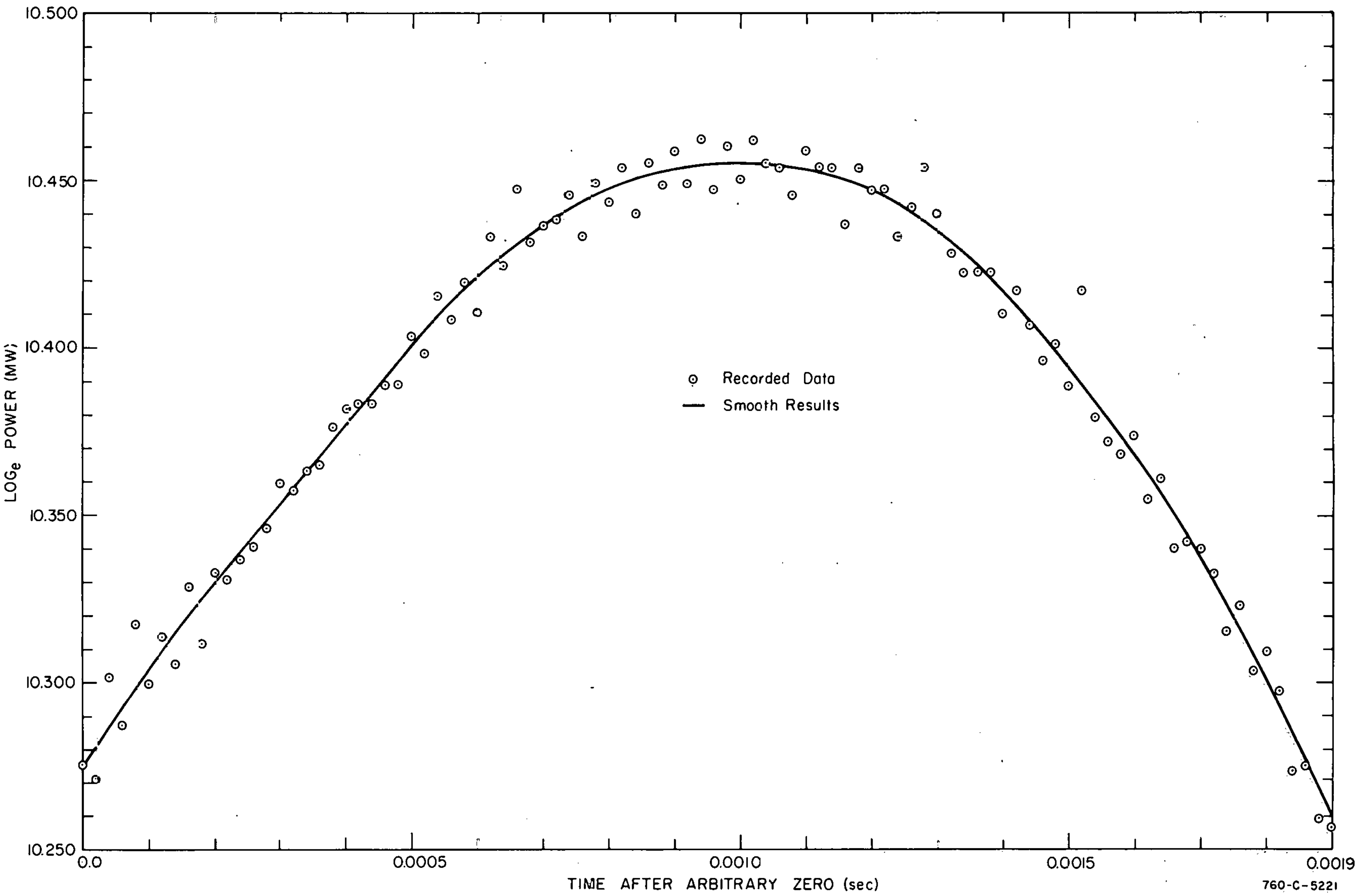

Fig. 23 Effect of smoothing data with small noise oscillations.

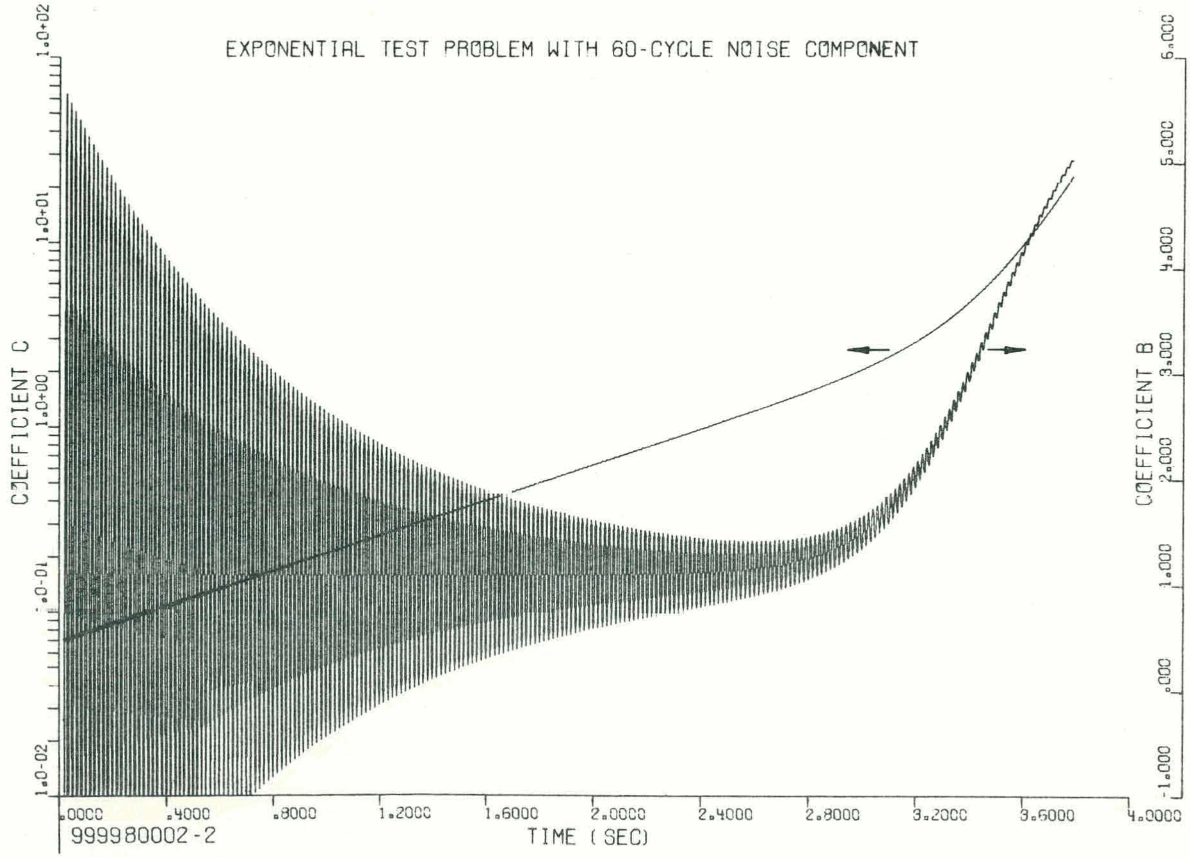

Fig. 24 Results of one smoothing pass on data which contain 60-cycle noise.

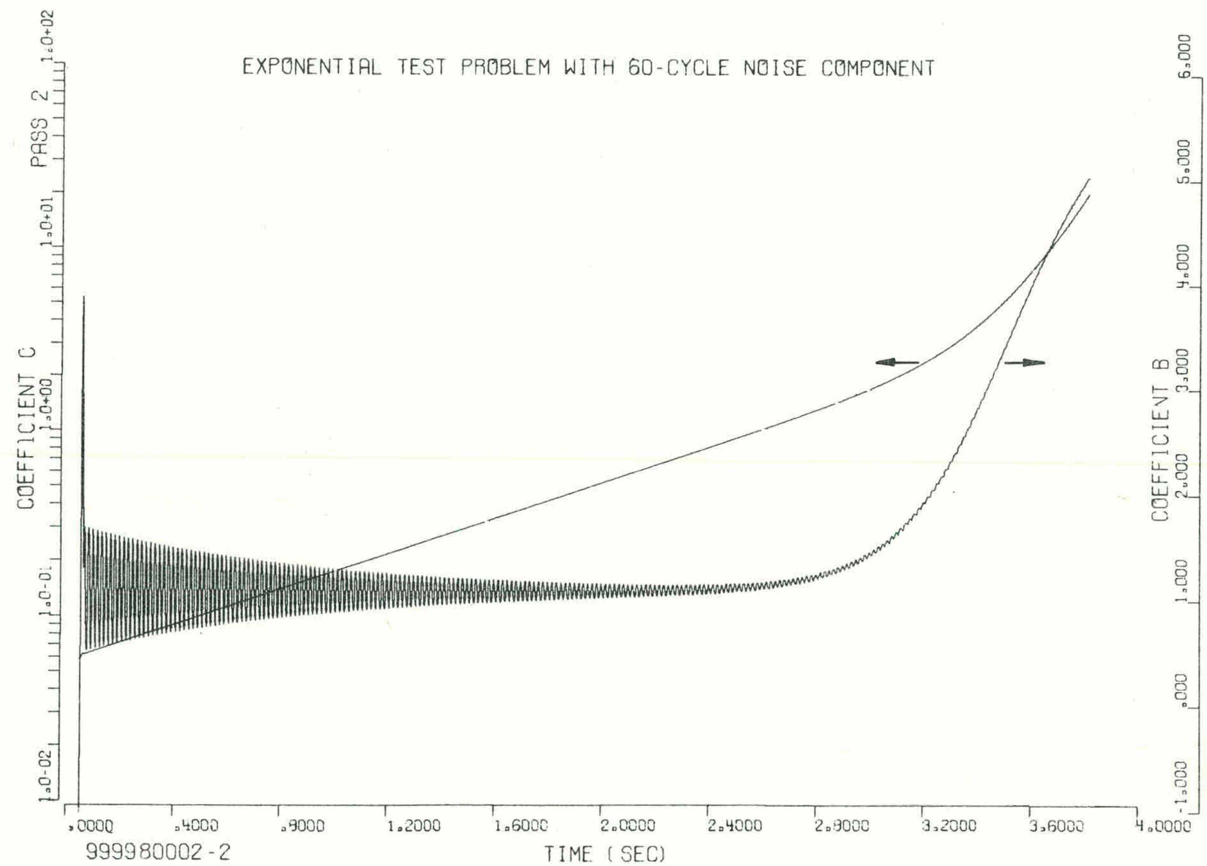

Fig. 25 Results of two smoothing passes on data which contain 60-cycle noise.

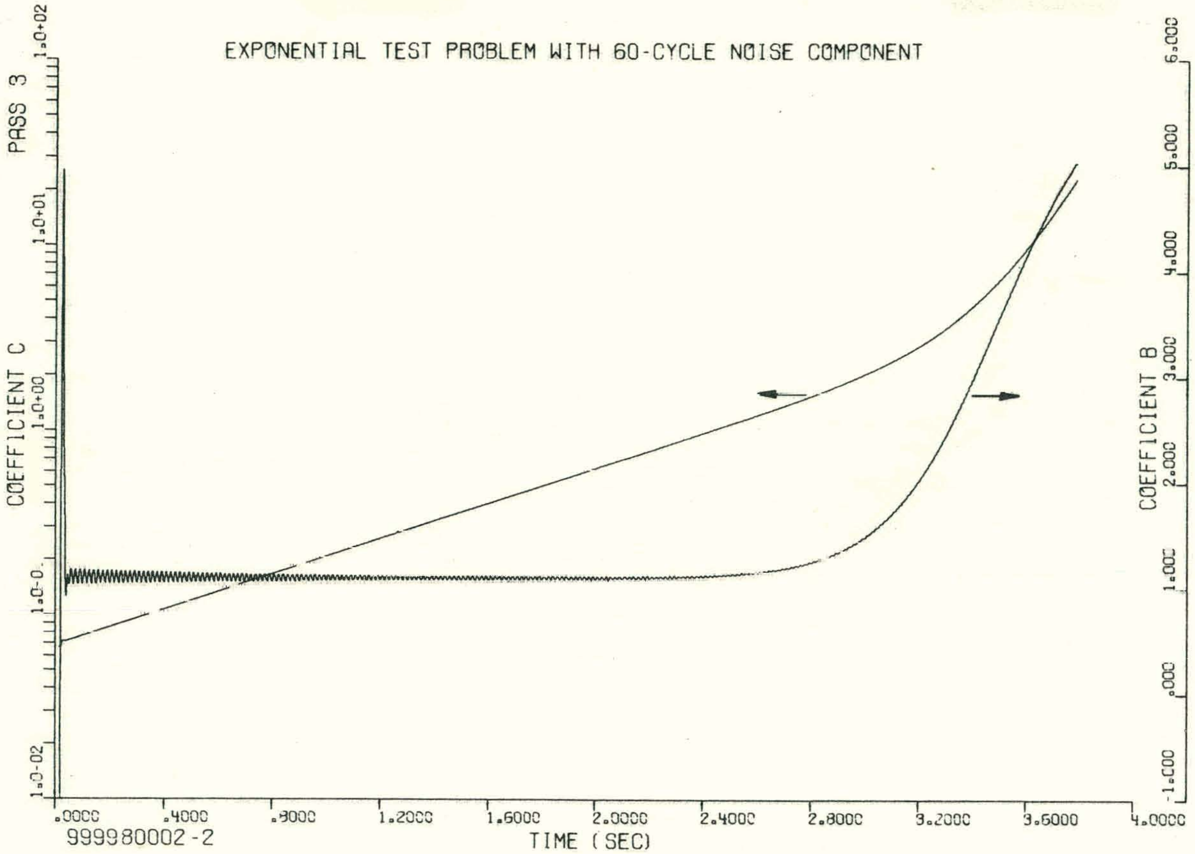

Fig. 26 Results of three smoothing passes on data which contain 60-cycle noise.

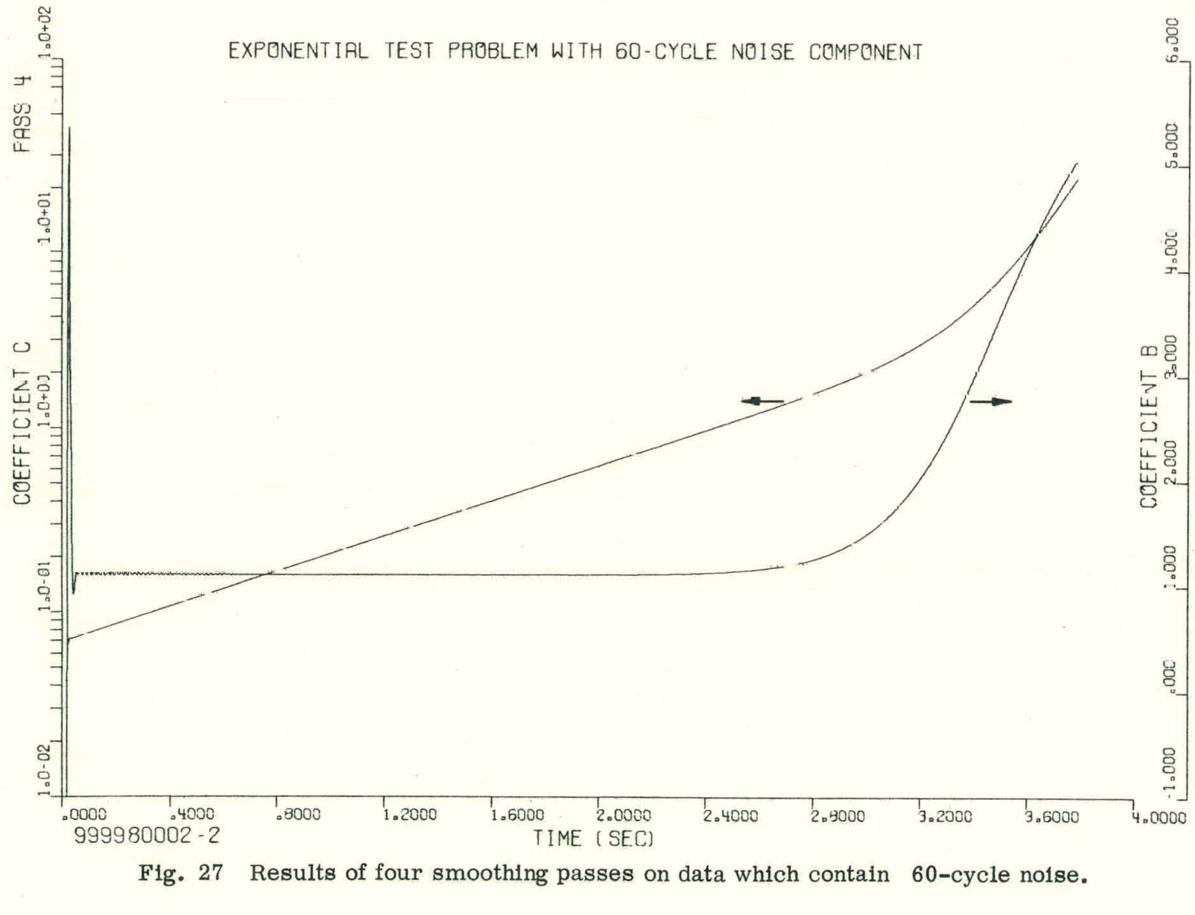

Fig. 27 Results of four smoothing passes on data which contain 60-cycle noise.

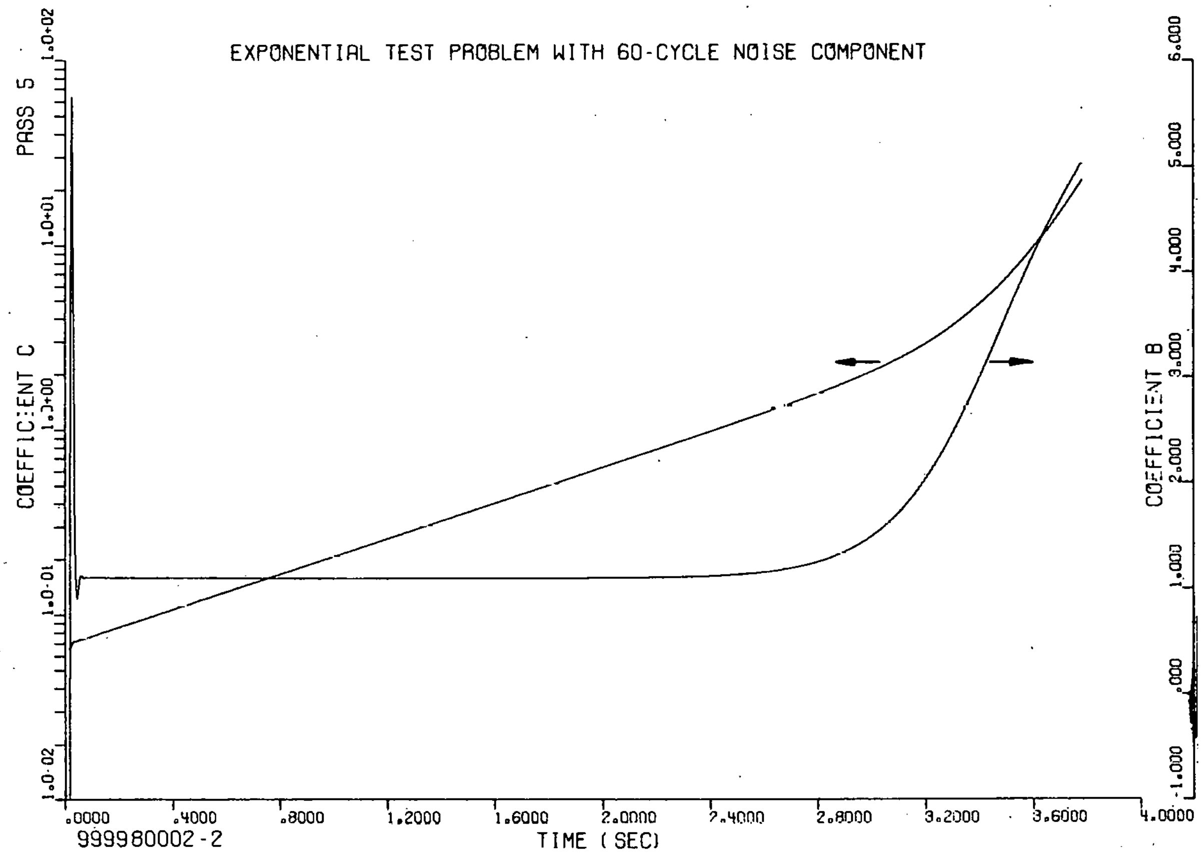

Fig. 28 Results of five smoothing passes on data which contain 60-cycle noise.

3. CHECKOUT OF REACTIVITY

To determine that the calculations made by REACTIVITY were correct, power data given by the equation

$$\phi(t) = \phi(o)e^{\alpha t} \tag{167}$$

were generated and processed by REACTIVITY. For the constants used in the test problem, the reactivity should be given by

$$\$(t) = 1.1415 - 0.002e^{-50t} \quad . \tag{168}$$

(Note that the initial reactivity value is calculated from the inhour equation which ignores the source term.) Listings of the first two pages and the last page of REACTIVITY outputs are shown on pages 96 through 99, and a plot of the calculated reactivity is given in Figure 29. These results indicate that the desired calculations are being made correctly.

An additional test which was applied to REACTIVITY is that of Spert I Transient 13398. In this particular transient, a reactivity step insertion of 91¢ was applied to the reactor resulting in an initial exponential power rise with a period of approximately 31.1 msec. Before the reactor power was

REACTIVITY PROGRAM

TEST PROBLEM TO CHECK THE ACCURACY OF SMOOTH AND REACTIVITY

	LAMBDA / BETA BAR	INITIAL AVERAGE RECIPR. PERIOD	DG ER LO AU YP PS	P C C O N	L I I N S T N E G	I N T E N	PRE NTN PPP LLL ITT	S C A L E S	INITIAL ENERGY	SOURCE
CONTROL CARD WAS-	0.003000C0	50.00000000	6	0	0	0	300	00	0.	2.00000000

LAMBDA'S

0.012700000	0.031700000	0.116000000	0.311000001	1.400000006	3.870000005

F'S

0.038000000	0.213000000	0.187999999	0.407000002	0.128000000	0.026000000

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 888

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
888888888	0.000600	3.0914	1.1415501	0.	0.061827	0.
888888888	0.000650	3.0991	1.1396141	-0.0019360	0.061982	-0.031235399
888888888	0.000700	3.1069	1.1396189	-0.0019312	0.062137	-0.031079710
888888888	0.000750	3.1146	1.1396237	-0.0019264	0.062293	-0.030924603
888888888	0.000800	3.1224	1.1396285	-0.0019216	0.062449	-0.030770315
888888888	0.000850	3.1302	1.1396333	-0.0019168	0.062605	-0.030616844
888888888	0.000900	3.1381	1.1396381	-0.0019120	0.062762	-0.030464184
888888888	0.000950	3.1459	1.1396429	-0.0019072	0.062919	-0.030312333
888888888	0.001000	3.1538	1.1396477	-0.0019024	0.063076	-0.030161050
888888888	0.001050	3.1617	1.1396524	-0.0018977	0.063234	-0.030010805
888888888	0.001100	3.1696	1.1396571	-0.0018930	0.063392	-0.029861122
888888888	0.001150	3.1776	1.1396619	-0.0018882	0.063551	-0.029711999
888888888	0.001200	3.1855	1.1396666	-0.0018835	0.063710	-0.029563903
888888888	0.001250	3.1935	1.1396713	-0.0018788	0.063870	-0.029416594
888888888	0.001300	3.2015	1.1396760	-0.0018741	0.064030	-0.029269837
888888888	0.001350	3.2095	1.1396807	-0.0018695	0.064190	-0.029123862
888888888	0.001400	3.2175	1.1396853	-0.0018648	0.064350	-0.028978664
888888888	0.001450	3.2256	1.1396900	-0.0018601	0.064512	-0.028834241
888888888	0.001500	3.2337	1.1396946	-0.0018555	0.064673	-0.028690128
888888888	0.001550	3.2417	1.1396993	-0.0018508	0.064835	-0.028547015
888888888	0.001600	3.2499	1.1397039	-0.0018462	0.064997	-0.028404667
888888888	0.001650	3.2580	1.1397085	-0.0018416	0.065160	-0.028262851
888888888	0.001700	3.2662	1.1397131	-0.0018370	0.065323	-0.028122251
888888888	0.001750	3.2743	1.1397177	-0.0018324	0.065487	-0.027981722
888888888	0.001800	3.2825	1.1397223	-0.0018279	0.065650	-0.027842173
888888888	0.001850	3.2907	1.1397268	-0.0018233	0.065815	-0.027703147
888888888	0.001900	3.2990	1.1397314	-0.0018187	0.065980	-0.027565093
888888888	0.001950	3.3072	1.1397359	-0.0018142	0.066145	-0.027427556
888888888	0.002000	3.3155	1.1397405	-0.0018097	0.066310	-0.027290758
888888888	0.002050	3.3238	1.1397450	-0.0018051	0.066476	-0.027154473
888888888	0.002100	3.3321	1.1397495	-0.0018006	0.066643	-0.027019145
888888888	0.002150	3.3405	1.1397540	-0.0017961	0.066809	-0.026884323
888888888	0.002200	3.3488	1.1397585	-0.0017916	0.066977	-0.026750229
888888888	0.002250	3.3572	1.1397629	-0.0017872	0.067144	-0.026616859
888888888	0.002300	3.3656	1.1397674	-0.0017827	0.067312	-0.026484210
888888888	0.002350	3.3740	1.1397719	-0.0017782	0.067481	-0.026351836
888888888	0.002400	3.3825	1.1397763	-0.0017738	0.067650	-0.026220398
888888888	0.002450	3.3910	1.1397807	-0.0017694	0.067819	-0.026089673
888888888	0.002500	3.3994	1.1397852	-0.0017650	0.067989	-0.025959436
888888888	0.002550	3.4080	1.1397896	-0.0017605	0.068159	-0.025829907
888888888	0.002600	3.4165	1.1397939	-0.0017562	0.068330	-0.025701298
888888888	0.002650	3.4250	1.1397983	-0.0017518	0.068501	-0.025573170
888888888	0.002700	3.4336	1.1398027	-0.0017474	0.068672	-0.025445522
888888888	0.002750	3.4422	1.1398071	-0.0017430	0.068844	-0.025318569
888888888	0.002800	3.4508	1.1398114	-0.0017387	0.069016	-0.025192522
888888888	0.002850	3.4595	1.1398157	-0.0017344	0.069189	-0.025066948
888888888	0.002900	3.4681	1.1398201	-0.0017300	0.069362	-0.024942058
888888888	0.002950	3.4768	1.1398244	-0.0017257	0.069536	-0.024817635
888888888	0.003000	3.4855	1.1398287	-0.0017214	0.069710	-0.024693679
888888888	0.003050	3.4942	1.1398330	-0.0017171	0.069885	-0.024570613

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 888

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
888888888	0.003100	3.5030	1.1398373	-0.0017128	0.070059	-0.024447795
888888888	0.003150	3.5117	1.1398416	-0.0017085	0.070235	-0.024325861
888888888	0.003200	3.5205	1.1398458	-0.0017043	0.070411	-0.024204596
888888888	0.003250	3.5293	1.1398501	-0.0017000	0.070587	-0.024083995
888888888	0.003300	3.5382	1.1398543	-0.0016958	0.070764	-0.023963846
888888888	0.003350	3.5470	1.1398586	-0.0016915	0.070941	-0.023844357
888888888	0.003400	3.5559	1.1398628	-0.0016873	0.071118	-0.023725525
888888888	0.003450	3.5648	1.1398670	-0.0016831	0.071296	-0.023607346
888888888	0.003500	3.5737	1.1398712	-0.0016789	0.071475	-0.023489610
888888888	0.003550	3.5827	1.1398754	-0.0016747	0.071654	-0.023372315
888888888	0.003600	3.5917	1.1398796	-0.0016705	0.071833	-0.023255666
888888888	0.003650	3.6006	1.1398838	-0.0016664	0.072013	-0.023139661
888888888	0.003700	3.6097	1.1398879	-0.0016622	0.072193	-0.023024296
888888888	0.003750	3.6187	1.1398921	-0.0016580	0.072374	-0.022909364
888888888	0.003800	3.6277	1.1398962	-0.0016539	0.072555	-0.022795067
888888888	0.003850	3.6368	1.1399003	-0.0016498	0.072737	-0.022681403
888888888	0.003900	3.6459	1.1399045	-0.0016456	0.072919	-0.022568165
888888888	0.003950	3.6551	1.1399086	-0.0016415	0.073101	-0.022455554
888888888	0.004000	3.6642	1.1399127	-0.0016374	0.073284	-0.022343365
888888888	0.004050	3.6734	1.1399168	-0.0016333	0.073468	-0.022232205
888888888	0.004100	3.6826	1.1399208	-0.0016293	0.073651	-0.022121259
888888888	0.004150	3.6918	1.1399249	-0.0016252	0.073836	-0.022010929
888888888	0.004200	3.7010	1.1399290	-0.0016211	0.074021	-0.021901013
888888888	0.004250	3.7103	1.1399330	-0.0016171	0.074206	-0.021791709
888888888	0.004300	3.7196	1.1399371	-0.0016130	0.074392	-0.021683015
888888888	0.004350	3.7289	1.1399411	-0.0016090	0.074578	-0.021574727
888888888	0.004400	3.7382	1.1399451	-0.0016050	0.074765	-0.021467244
888888888	0.004450	3.7476	1.1399491	-0.0016010	0.074952	-0.021359965
888888888	0.004500	3.7570	1.1399531	-0.0015970	0.075139	-0.021253483
888888888	0.004550	3.7664	1.1399571	-0.0015930	0.075327	-0.021147599
888888888	0.004600	3.7758	1.1399611	-0.0015890	0.075516	-0.021042110
888888888	0.004650	3.7853	1.1399651	-0.0015851	0.075705	-0.020937213
888888888	0.004700	3.7947	1.1399690	-0.0015811	0.075894	-0.020833102
888888888	0.004750	3.8042	1.1399730	-0.0015772	0.076084	-0.020728988
888888888	0.004800	3.8137	1.1399769	-0.0015732	0.076275	-0.020625850
888888888	0.004850	3.8233	1.1399808	-0.0015693	0.076466	-0.020522903
888888888	0.004900	3.8329	1.1399847	-0.0015654	0.076657	-0.020420731
888888888	0.004950	3.8425	1.1399886	-0.0015615	0.076849	-0.020318747
888888888	0.005000	3.8521	1.1399925	-0.0015576	0.077041	-0.020217532
888888888	0.005050	3.8617	1.1399964	-0.0015537	0.077234	-0.020116888
888888888	0.005100	3.8714	1.1400003	-0.0015498	0.077428	-0.020016429
888888888	0.005150	3.8811	1.1400042	-0.0015460	0.077621	-0.019916537
888888888	0.005200	3.8908	1.1400080	-0.0015421	0.077816	-0.019817212
888888888	0.005250	3.9005	1.1400119	-0.0015382	0.078011	-0.019718449
888888888	0.005300	3.9103	1.1400157	-0.0015344	0.078206	-0.019619865
888888888	0.005350	3.9201	1.1400196	-0.0015305	0.078402	-0.019521841
888888888	0.005400	3.9299	1.1400234	-0.0015267	0.078598	-0.019424563
888888888	0.005450	3.9397	1.1400272	-0.0015229	0.078795	-0.019327649
888888888	0.005500	3.9496	1.1400310	-0.0015191	0.078992	-0.019231098
888888888	0.005550	3.9595	1.1400348	-0.0015153	0.079190	-0.019135285

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 888

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
888888888	0.118100	1100.6010	1.1415448	-0.0000053	22.011969	-0.000000243
888888888	0.118150	1103.3559	1.1415448	-0.0000053	22.067068	-0.000000242
888888888	0.118200	1106.1178	1.1415447	-0.0000054	22.122304	-0.000000244
888888888	0.118250	1108.8863	1.1415447	-0.0000054	22.177679	-0.000000243
888888888	0.118300	1111.6618	1.1415447	-0.0000054	22.233193	-0.000000245
888888888	0.118350	1114.4451	1.1415447	-0.0000054	22.288846	-0.000000244
888888888	0.118400	1117.2346	1.1415447	-0.0000054	22.344637	-0.000000243
888888888	0.118450	1120.0311	1.1415447	-0.0000055	22.400569	-0.000000243
888888888	0.118500	1122.8347	1.1415447	-0.0000054	22.456640	-0.000000242
888888888	0.118550	1125.6451	1.1415447	-0.0000055	22.512852	-0.000000242
888888888	0.118600	1128.4626	1.1415447	-0.0000054	22.569205	-0.000000239
888888888	0.118650	1131.2873	1.1415447	-0.0000054	22.625699	-0.000000240
888888888	0.118700	1134.1194	1.1415447	-0.0000054	22.682334	-0.000000237
888888888	0.118750	1136.9580	1.1415447	-0.0000054	22.739110	-0.000000236
888888888	0.118800	1139.8040	1.1415448	-0.0000053	22.796029	-0.000000233
888888888	0.118850	1142.6571	1.1415448	-0.0000053	22.853091	-0.000000233
888888888	0.118900	1145.5175	1.1415448	-0.0000053	22.910295	-0.000000230
888888888	0.118950	1148.3846	1.1415449	-0.0000052	22.967642	-0.000000226
888888888	0.119000	1151.2593	1.1415450	-0.0000052	23.025133	-0.000000224
888888888	0.119050	1154.1409	1.1415450	-0.0000051	23.082768	-0.000000221
888888888	0.119100	1157.0301	1.1415451	-0.0000051	23.140547	-0.000000218
888888888	0.119150	1159.9262	1.1415451	-0.0000050	23.198471	-0.000000215
888888888	0.119200	1162.8297	1.1415452	-0.0000049	23.256540	-0.000000213
888888888	0.119250	1165.7401	1.1415451	-0.0000050	23.314754	-0.000000213
888888888	0.119300	1168.6584	1.1415452	-0.0000049	23.373114	-0.000000211
888888888	0.119350	1171.5837	1.1415452	-0.0000049	23.431620	-0.000000211
888888888	0.119400	1174.5162	1.1415452	-0.0000049	23.490272	-0.000000210

CALCULATIONS REQUIRED 2 MIN 1.3 SEC AND PLOT(S) REQUIRED 0 MIN 29.9 SEC

TOTAL PROBLEM TIME WAS 3 MIN 45.4 SEC

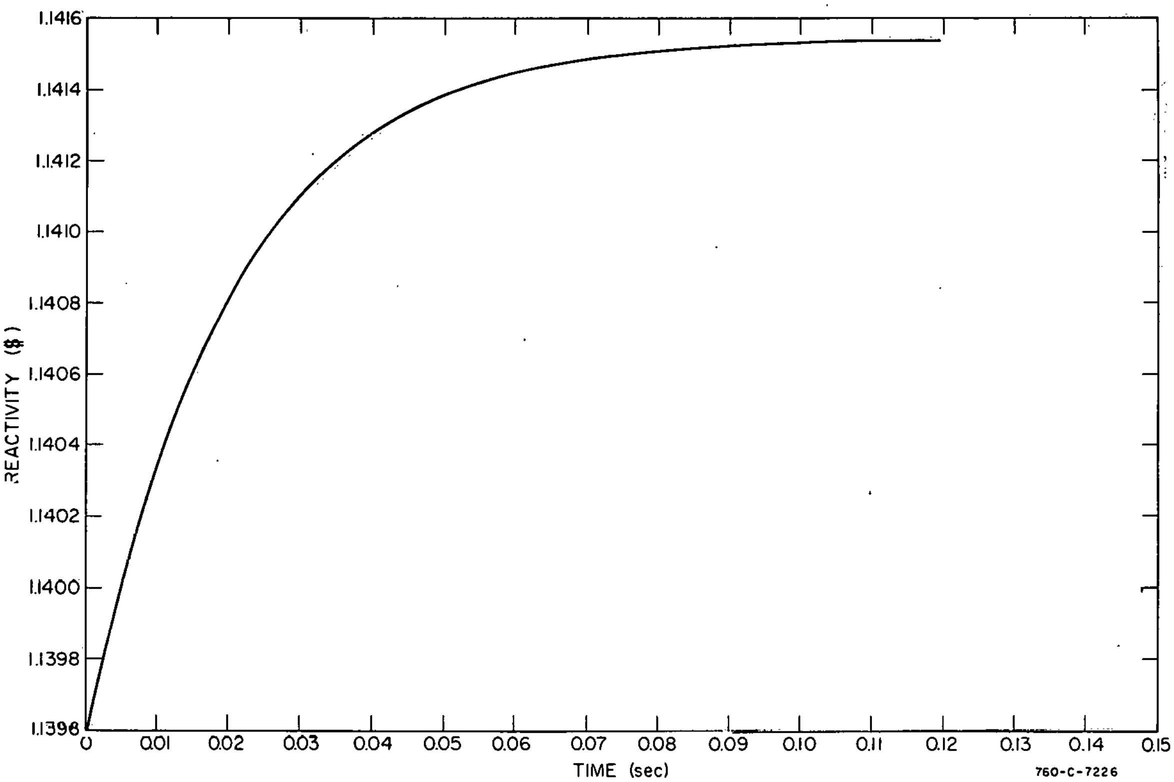

Fig. 29 REACTIVITY calculation on exponential test data.

sufficiently high to induce self-shutdown by the reactor, control rods were inserted at a constant, known rate. From the calibration of the control rods and the known rate of insertion, the reactivity of the system was calculated to decrease at a rate of 17¢/sec. This transient then provides a means of comparing the REACTIVITY program with a power transient in which the reactivity of the system is known.

A listing of the results of the REACTIVITY program is given on pages 101 through 105 and a plot in Figure 30. The answers obtained from REACTIVITY are well within experimental accuracy.

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SPORT  03/15/65            SPERT I  KNOWN RATE OF INSERTION - 17 CENTS/SECOND                           PAGE  4

REACTIVITY PROGRAM                                                        DG P L I PFE S
                                                                          ER C I N WTN C
                                                                          LO   S T     A
            SPERT I  KNOWN RATE OF INSERTION - 17 CENTS/SECOND            AU C T   PFP L
                                                                          YP O N E LLL E
                     LAMBDA / BETA BAR     INITIAL AVERAGE RECIPR. PERIOD PS N G N TTT S  INITIAL ENERGY    SOURCE

CONTROL CARD WAS-         0.00287000                 3.21000001           6 0 0 0 000 00  -0.               -0.

                                                  LAMBDA'S

    0.012700000   0.031700000   0.116000000   0.311000001   1.400000006   3.870000005

                                                    F'S

    0.038000000   0.213000000   0.187999999   0.407000002   0.128000000   0.026000000
```

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
20133981	1.425000	0.0016	0.9113902	0.	0.000508	0.
20133981	1.435000	0.0017	0.9120884	0.0006982	0.000524	1.332000017
20133981	1.445000	0.0017	0.9120458	0.0006556	0.000541	1.211124808
20133981	1.455000	0.0018	0.9120050	0.0006149	0.000559	1.099907696
20133981	1.465000	0.0019	0.9119378	0.0005476	0.000577	0.948507495
20133981	1.475000	0.0019	0.9118315	0.0004413	0.000596	0.740118459
20133981	1.485000	0.0020	0.9116994	0.0003092	0.000616	0.502131678
20133981	1.495000	0.0020	0.9115547	0.0001646	0.000636	0.258780934
20133981	1.505000	0.0021	0.9113986	0.0000084	0.000657	0.012808031
20133981	1.515000	0.0022	0.9112265	-0.0001637	0.000678	-0.241290793
20133981	1.525000	0.0023	0.9110244	-0.0003658	0.000700	-0.522263221
20133981	1.535000	0.0023	0.9107678	-0.0006224	0.000723	-0.860528246
20133981	1.545000	0.0024	0.9104304	-0.0009597	0.000747	-1.285126075
20133981	1.555000	0.0025	0.9100570	-0.0013332	0.000771	-1.728978544
20133981	1.565000	0.0025	0.9096720	-0.0017181	0.000796	-2.158400506
20133981	1.575000	0.0026	0.9093023	-0.0020879	0.000822	-2.540856272
20133981	1.585000	0.0027	0.9089556	-0.0024345	0.000848	-2.870405883
20133981	1.595000	0.0028	0.9086413	-0.0027488	0.000875	-3.140341789
20133981	1.605000	0.0028	0.9083645	-0.0030257	0.000903	-3.349598467
20133981	1.615000	0.0029	0.9081085	-0.0032817	0.000932	-3.520798475
20133981	1.625000	0.0030	0.9078882	-0.0035020	0.000962	-3.641344249
20133981	1.635000	0.0031	0.9076954	-0.0036948	0.000992	-3.723750204
20133981	1.645000	0.0032	0.9075082	-0.0038820	0.001024	-3.792393029
20133981	1.655000	0.0033	0.9073154	-0.0040747	0.001056	-3.858794630
20133981	1.665000	0.0034	0.9070989	-0.0042912	0.001089	-3.939651012
20133981	1.675000	0.0035	0.9068549	-0.0045353	0.001123	-4.036754429
20133981	1.685000	0.0036	0.9065882	-0.0048020	0.001159	-4.144254327
20133981	1.695000	0.0037	0.9063101	-0.0050801	0.001195	-4.251358926
20133981	1.705000	0.0038	0.9060505	-0.0053397	0.001232	-4.333565593
20133981	1.715000	0.0039	0.9058262	-0.0055639	0.001270	-4.379535019
20133981	1.725000	0.0040	0.9056611	-0.0057291	0.001310	-4.374061882
20133981	1.735000	0.0041	0.9055732	-0.0058170	0.001350	-4.308037519
20133981	1.745000	0.0042	0.9055772	-0.0058130	0.001392	-4.176290274
20133981	1.755000	0.0044	0.9056886	-0.0057015	0.001435	-3.973870367
20133981	1.765000	0.0045	0.9059135	-0.0054766	0.001479	-3.703147203
20133981	1.775000	0.0046	0.9062476	-0.0051426	0.001524	-3.373427421
20133981	1.785000	0.0048	0.9066816	-0.0047085	0.001571	-2.996331662
20133981	1.795000	0.0049	0.9072019	-0.0041882	0.001620	-2.585353702
20133981	1.805000	0.0051	0.9077855	-0.0036047	0.001670	-2.158228219
20133981	1.815000	0.0053	0.9084038	-0.0029864	0.001722	-1.734036580
20133981	1.825000	0.0055	0.9090171	-0.0023730	0.001776	-1.336109161
20133981	1.835000	0.0057	0.9095891	-0.0018011	0.001832	-0.983152799
20133981	1.845000	0.0059	0.9100888	-0.0013014	0.001890	-0.688581787
20133981	1.855000	0.0061	0.9104727	-0.0009175	0.001950	-0.470483061
20133981	1.865000	0.0063	0.9107053	-0.0006849	0.002012	-0.340326738
20133981	1.875000	0.0066	0.9107555	-0.0006347	0.002077	-0.305574030
20133981	1.885000	0.0068	0.9105917	-0.0007984	0.002144	-0.372465719
20133981	1.895000	0.0070	0.9102404	-0.0011497	0.002213	-0.519623816
20133981	1.905000	0.0072	0.9097476	-0.0016425	0.002284	-0.719279155
20133981	1.915000	0.0074	0.9091785	-0.0022116	0.002357	-0.938471794

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
20133981	1.925000	0.0076	0.9085974	-0.0027927	0.002432	-1.148494124
20133981	1.935000	0.0078	0.9080673	-0.0033228	0.002509	-1.324508250
20133981	1.945000	0.0080	0.9076467	-0.0037435	0.002588	-1.446547508
20133981	1.955000	0.0082	0.9073757	-0.0040144	0.002669	-1.504020423
20133981	1.965000	0.0085	0.9072788	-0.0041114	0.002753	-1.493572444
20133981	1.975000	0.0087	0.9073662	-0.0040240	0.002839	-1.417513594
20133981	1.985000	0.0090	0.9076255	-0.0037647	0.002927	-1.285975203
20133981	1.995000	0.0093	0.9080160	-0.0033742	0.003019	-1.117609099
20133981	2.005000	0.0096	0.9084705	-0.0029196	0.003114	-0.937616497
20133981	2.015000	0.0100	0.9089093	-0.0024808	0.003212	-0.772375993
20133981	2.025000	0.0103	0.9092494	-0.0021408	0.003313	-0.646072343
20133981	2.035000	0.0107	0.9094453	-0.0019449	0.003419	-0.568922870
20133981	2.045000	0.0110	0.9094858	-0.0019043	0.003527	-0.539889194
20133981	2.055000	0.0114	0.9093678	-0.0020224	0.003639	-0.555678844
20133981	2.065000	0.0118	0.9090963	-0.0022938	0.003755	-0.610830560
20133981	2.075000	0.0121	0.9086985	-0.0026917	0.003875	-0.694714770
20133981	2.085000	0.0125	0.9082162	-0.0031739	0.003997	-0.794028431
20133981	2.095000	0.0128	0.9077047	-0.0036855	0.004123	-0.893798128
20133981	2.105000	0.0131	0.9072185	-0.0041717	0.004253	-0.980903886
20133981	2.115000	0.0135	0.9068150	-0.0045752	0.004386	-1.043142512
20133981	2.125000	0.0139	0.9065387	-0.0048514	0.004523	-1.072695673
20133981	2.135000	0.0143	0.9064149	-0.0049753	0.004663	-1.066927701
20133981	2.145000	0.0147	0.9064450	-0.0049452	0.004808	-1.028586105
20133981	2.155000	0.0151	0.9066162	-0.0047740	0.004957	-0.963147841
20133981	2.165000	0.0156	0.9068984	-0.0044918	0.005110	-0.878974244
20133981	2.175000	0.0161	0.9072613	-0.0041289	0.005269	-0.783663295
20133981	2.185000	0.0166	0.9076886	-0.0037015	0.005432	-0.681374937
20133981	2.195000	0.0172	0.9081515	-0.0032386	0.005602	-0.578148715
20133981	2.205000	0.0178	0.9086187	-0.0027715	0.005777	-0.479757167
20133981	2.215000	0.0184	0.9090605	-0.0023297	0.005958	-0.391016286
20133981	2.225000	0.0191	0.9094571	-0.0019330	0.006146	-0.314534768
20133981	2.235000	0.0198	0.9097954	-0.0015948	0.006340	-0.251546964
20133981	2.245000	0.0204	0.9100598	-0.0013304	0.006541	-0.203396156
20133981	2.255000	0.0212	0.9102474	-0.0011427	0.006749	-0.169318682
20133981	2.265000	0.0219	0.9103607	-0.0010295	0.006964	-0.147824226
20133981	2.275000	0.0226	0.9104066	-0.0009836	0.007187	-0.136862850
20133981	2.285000	0.0234	0.9103844	-0.0010058	0.007417	-0.135612121
20133981	2.295000	0.0241	0.9103016	-0.0010886	0.007654	-0.142223516
20133981	2.305000	0.0249	0.9101722	-0.0012180	0.007899	-0.154191429
20133981	2.315000	0.0257	0.9100216	-0.0013686	0.008152	-0.167888502
20133981	2.325000	0.0265	0.9098741	-0.0015160	0.008412	-0.180213528
20133981	2.335000	0.0273	0.9097532	-0.0016370	0.008681	-0.188567240
20133981	2.345000	0.0281	0.9096639	-0.0017262	0.008958	-0.192700526
20133981	2.355000	0.0290	0.9095924	-0.0017977	0.009244	-0.194473758
20133981	2.365000	0.0300	0.9095357	-0.0018544	0.009539	-0.194406372
20133981	2.375000	0.0309	0.9094808	-0.0019093	0.009843	-0.193972522
20133981	2.385000	0.0319	0.9094043	-0.0019859	0.010157	-0.195514079
20133981	2.395000	0.0329	0.9093031	-0.0020870	0.010481	-0.199122330
20133981	2.405000	0.0339	0.9091733	-0.0022168	0.010815	-0.204975959
20133981	2.415000	0.0350	0.9090095	-0.0023807	0.011159	-0.213331200

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
20133981	2.425000	0.0360	0.9087903	-0.0025999	0.011514	-0.225793611
20133981	2.435000	0.0371	0.9085183	-0.0028718	0.011880	-0.241742099
20133981	2.445000	0.0382	0.9082191	-0.0031711	0.012256	-0.258738451
20133981	2.455000	0.0393	0.9079230	-0.0034672	0.012643	-0.274242055
20133981	2.465000	0.0404	0.9076624	-0.0037278	0.013041	-0.285850003
20133981	2.475000	0.0416	0.9074644	-0.0039257	0.013451	-0.291862804
20133981	2.485000	0.0428	0.9073269	-0.0040633	0.013872	-0.292905901
20133981	2.495000	0.0441	0.9072429	-0.0041473	0.014306	-0.289890405
20133981	2.505000	0.0454	0.9072215	-0.0041687	0.014753	-0.282557640
20133981	2.515000	0.0468	0.9072543	-0.0041358	0.015214	-0.271841578
20133981	2.525000	0.0482	0.9073293	-0.0040608	0.015689	-0.258833844
20133981	2.535000	0.0497	0.9074436	-0.0039465	0.016179	-0.243934235
20133981	2.545000	0.0513	0.9075813	-0.0038089	0.016684	-0.228296459
20133981	2.555000	0.0530	0.9077210	-0.0036692	0.017205	-0.213261338
20133981	2.565000	0.0546	0.9078413	-0.0035488	0.017743	-0.200009227
20133981	2.575000	0.0564	0.9079398	-0.0034504	0.018299	-0.188560858
20133981	2.585000	0.0582	0.9080205	-0.0033697	0.018872	-0.178557238
20133981	2.595000	0.0601	0.9080855	-0.0033047	0.019463	-0.169794122
20133981	2.605000	0.0620	0.9081380	-0.0032521	0.020073	-0.162012639
20133981	2.615000	0.0640	0.9081722	-0.0032180	0.020703	-0.155435028
20133981	2.625000	0.0660	0.9081800	-0.0032101	0.021353	-0.150335712
20133981	2.635000	0.0681	0.9081604	-0.0032297	0.022024	-0.146648156
20133981	2.645000	0.0702	0.9081223	-0.0032678	0.022715	-0.143861959
20133981	2.655000	0.0724	0.9080691	-0.0033211	0.023428	-0.141755417
20133981	2.665000	0.0747	0.9080022	-0.0033880	0.024164	-0.140208205
20133981	2.675000	0.0770	0.9079161	-0.0034740	0.024922	-0.139395736
20133981	2.685000	0.0794	0.9078112	-0.0035789	0.025704	-0.139238114
20133981	2.695000	0.0818	0.9076896	-0.0037006	0.026509	-0.139594283
20133981	2.705000	0.0843	0.9075505	-0.0038397	0.027340	-0.140442761
20133981	2.715000	0.0868	0.9073906	-0.0039996	0.028195	-0.141852846
20133981	2.725000	0.0894	0.9072073	-0.0041829	0.029077	-0.143857382
20133981	2.735000	0.0921	0.9069931	-0.0043971	0.029985	-0.146645403
20133981	2.745000	0.0948	0.9067426	-0.0046476	0.030919	-0.150312224
20133981	2.755000	0.0976	0.9064435	-0.0049467	0.031882	-0.155157369
20133981	2.765000	0.1004	0.9060938	-0.0052963	0.032872	-0.161120543
20133981	2.775000	0.1032	0.9056845	-0.0057056	0.033890	-0.168355877
20133981	2.785000	0.1061	0.9052157	-0.0061745	0.034937	-0.176731406
20133981	2.795000	0.1090	0.9046825	-0.0067077	0.036013	-0.186258974
20133981	2.805000	0.1118	0.9040775	-0.0073127	0.037117	-0.197018020
20133981	2.815000	0.1147	0.9033853	-0.0080049	0.038250	-0.209278753
20133981	2.825000	0.1176	0.9026070	-0.0087831	0.039411	-0.222857080
20133981	2.835000	0.1204	0.9017377	-0.0096524	0.040601	-0.237736957
20133981	2.845000	0.1231	0.9007728	-0.0106173	0.041819	-0.253888052
20133981	2.855000	0.1258	0.8997069	-0.0116832	0.043064	-0.271301609
20133981	2.865000	0.1284	0.8985382	-0.0128520	0.044335	-0.289885066
20133981	2.875000	0.1309	0.8972648	-0.0141253	0.045631	-0.309553616
20133981	2.885000	0.1333	0.8958919	-0.0154983	0.046952	-0.330087103
20133981	2.895000	0.1355	0.8944213	-0.0169688	0.048296	-0.351352081
20133981	2.905000	0.1376	0.8928660	-0.0185242	0.049661	-0.373009771
20133981	2.915000	0.1396	0.8912436	-0.0201466	0.051047	-0.394664712

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
20133981	2.925000	0.1415	0.8895715	-0.0218186	0.052453	-0.415967170
20133981	2.935000	0.1433	0.8878747	-0.0235154	0.053877	-0.436467070
20133981	2.945000	0.1451	0.8861642	-0.0252260	0.055318	-0.456013806
20133981	2.955000	0.1468	0.8844472	-0.0269430	0.056777	-0.474537898
20133981	2.965000	0.1484	0.8827327	-0.0286575	0.058253	-0.491951123
20133981	2.975000	0.1500	0.8810302	-0.0303600	0.059744	-0.508165911
20133981	2.985000	0.1515	0.8793416	-0.0320486	0.061252	-0.523227535
20133981	2.995000	0.1531	0.8776633	-0.0337268	0.062775	-0.537266038
20133981	3.005000	0.1546	0.8759924	-0.0353978	0.064313	-0.550394937
20133981	3.015000	0.1561	0.8743227	-0.0370675	0.065867	-0.562762745
20133981	3.025000	0.1576	0.8726482	-0.0387419	0.067435	-0.574505560
20133981	3.035000	0.1590	0.8709684	-0.0404218	0.069018	-0.585672021
20133981	3.045000	0.1603	0.8692860	-0.0421042	0.070614	-0.596256770
20133981	3.055000	0.1617	0.8676114	-0.0437787	0.072224	-0.606149167
20133981	3.065000	0.1630	0.8659456	-0.0454445	0.073848	-0.615379550
20133981	3.075000	0.1644	0.8642989	-0.0470913	0.075485	-0.623849839
20133981	3.085000	0.1657	0.8626638	-0.0487264	0.077135	-0.631701715
20133981	3.095000	0.1670	0.8610423	-0.0503479	0.078799	-0.638944350
20133981	3.105000	0.1683	0.8594316	-0.0519586	0.080475	-0.645648509
20133981	3.115000	0.1696	0.8578321	-0.0535581	0.082164	-0.651839934
20133981	3.125000	0.1709	0.8562340	-0.0551562	0.083867	-0.657664336
20133981	3.135000	0.1721	0.8546330	-0.0567571	0.085582	-0.663192511
20133981	3.145000	0.1733	0.8530231	-0.0583670	0.087309	-0.668511681
20133981	3.155000	0.1745	0.8513963	-0.0599939	0.089048	-0.673723377
20133981	3.165000	0.1757	0.8497519	-0.0616383	0.090799	-0.678842224
20133981	3.175000	0.1768	0.8480964	-0.0632938	0.092561	-0.683804341
20133981	3.185000	0.1778	0.8464297	-0.0649605	0.094334	-0.688620202
20133981	3.195000	0.1789	0.8447596	-0.0666306	0.096118	-0.693217099
20133981	3.205000	0.1799	0.8430863	-0.0683038	0.097912	-0.697604947
20133981	3.215000	0.1809	0.8414119	-0.0699783	0.099716	-0.701776251
20133981	3.225000	0.1819	0.8397371	-0.0716531	0.101530	-0.705734953
20133981	3.235000	0.1828	0.8380633	-0.0733269	0.103353	-0.709479384
20133981	3.245000	0.1837	0.8363890	-0.0750012	0.105186	-0.713035151
20133981	3.255000	0.1846	0.8347114	-0.0766787	0.107028	-0.716438867
20133981	3.265000	0.1855	0.8330298	-0.0783604	0.108878	-0.719706908
20133981	3.275000	0.1863	0.8313463	-0.0800438	0.110737	-0.722826272
20133981	3.285000	0.1872	0.8296601	-0.0817300	0.112605	-0.725813590
20133981	3.295000	0.1879	0.8279711	-0.0834191	0.114480	-0.728677653
20133981	3.305000	0.1887	0.8262829	-0.0851073	0.116363	-0.731392711
20133981	3.315000	0.1895	0.8245989	-0.0867912	0.118254	-0.733938426
20133981	3.325000	0.1902	0.8229213	-0.0884689	0.120152	-0.736306101
20133981	3.335000	0.1909	0.8212552	-0.0901349	0.122058	-0.738460913
20133981	3.345000	0.1916	0.8195998	-0.0917904	0.123971	-0.740420789
20133981	3.355000	0.1923	0.8179547	-0.0934355	0.125890	-0.742197074
20133981	3.365000	0.1930	0.8163193	-0.0950709	0.127817	-0.743803024
20133981	3.375000	0.1937	0.8146961	-0.0966941	0.129751	-0.745227948
20133981	3.385000	0.1944	0.8130834	-0.0983068	0.131692	-0.746491618
20133981	3.395000	0.1951	0.8114723	-0.0999179	0.133639	-0.747668609
20133981	3.405000	0.1957	0.8098599	-0.1015303	0.135593	-0.748784371
20133981	3.415000	0.1964	0.8082468	-0.1031434	0.137554	-0.749838203

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	P(T)
20133981	3.425000	0.1970	0.8066287	-0.1047614	0.139521	-0.750863820
20133981	3.435000	0.1976	0.8050011	-0.1063891	0.141494	-0.751896054
20133981	3.445000	0.1982	0.8033596	-0.1080305	0.143473	-0.752965234
20133981	3.455000	0.1987	0.8017070	-0.1096832	0.145458	-0.754052721
20133981	3.465000	0.1993	0.8000405	-0.1113497	0.147448	-0.755177490
20133981	3.475000	0.1998	0.7983519	-0.1130383	0.149444	-0.756394505
20133981	3.485000	0.2002	0.7966378	-0.1147524	0.151443	-0.757724158
20133981	3.495000	0.2006	0.7948968	-0.1164933	0.153448	-0.759172954
20133981	3.505000	0.2010	0.7931311	-0.1182591	0.155456	-0.760725185
20133981	3.515000	0.2013	0.7913480	-0.1200421	0.157467	-0.762330353
20133981	3.525000	0.2016	0.7895462	-0.1218439	0.159482	-0.763997674
20133981	3.535000	0.2019	0.7877203	-0.1236699	0.161500	-0.765759930
20133981	3.545000	0.2021	0.7858759	-0.1255143	0.163519	-0.767580412
20133981	3.555000	0.2023	0.7840241	-0.1273660	0.165541	-0.769391239
20133981	3.565000	0.2025	0.7821706	-0.1292195	0.167565	-0.771160394
20133981	3.575000	0.2026	0.7803223	-0.1310679	0.169590	-0.772849433
20133981	3.585000	0.2028	0.7784864	-0.1329038	0.171617	-0.774419501
20133981	3.595000	0.2029	0.7766673	-0.1347228	0.173646	-0.775848851
20133981	3.605000	0.2031	0.7748634	-0.1365267	0.175675	-0.777153127
20133981	3.615000	0.2032	0.7730794	-0.1383108	0.177707	-0.778309479
20133981	3.625000	0.2033	0.7713198	-0.1400703	0.179739	-0.779297329
20133981	3.635000	0.2035	0.7695879	-0.1418023	0.181773	-0.780104309
20133981	3.645000	0.2037	0.7678826	-0.1435076	0.183809	-0.780741550
20133981	3.655000	0.2038	0.7661991	-0.1451911	0.185847	-0.781239763
20133981	3.665000	0.2040	0.7645299	-0.1468603	0.187886	-0.781644002
20133981	3.675000	0.2042	0.7628673	-0.1485229	0.189928	-0.781997189
20133981	3.685000	0.2044	0.7612104	-0.1501798	0.191971	-0.782306135
20133981	3.695000	0.2046	0.7595609	-0.1518293	0.194015	-0.782563239
20133981	3.705000	0.2047	0.7579130	-0.1534771	0.196062	-0.782799557
20133981	3.715000	0.2049	0.7562548	-0.1551353	0.198110	-0.783077016
20133981	3.725000	0.2050	0.7545786	-0.1568116	0.200159	-0.783433564
20133981	3.735000	0.2051	0.7528789	-0.1585113	0.202210	-0.783894315
20133981	3.745000	0.2052	0.7511576	-0.1602326	0.204261	-0.784448475
20133981	3.755000	0.2052	0.7494192	-0.1619710	0.206314	-0.785071999
20133981	3.765000	0.2053	0.7476639	-0.1637263	0.208366	-0.785762936
20133981	3.775000	0.2053	0.7458887	-0.1655014	0.210419	-0.786534511
20133981	3.785000	0.2052	0.7440939	-0.1672963	0.212471	-0.787384845
20133981	3.795000	0.2052	0.7422894	-0.1691008	0.214523	-0.788265258
20133981	3.805000	0.2051	0.7404874	-0.1709027	0.216574	-0.789119929
20133981	3.815000	0.2050	0.7387016	-0.1726886	0.218624	-0.789887026
20133981	3.825000	0.2050	0.7369434	-0.1744468	0.220674	-0.790516719
20133981	3.835000	0.2049	0.7352244	-0.1761658	0.222724	-0.790960498
20133981	3.845000	0.2049	0.7335426	-0.1778476	0.224773	-0.791231334
20133981	3.855000	0.2049	0.7318861	-0.1795040	0.226822	-0.791386023
20133981	3.865000	0.2049	0.7302520	-0.1811382	0.228872	-0.791440554
20133981	3.875000	0.2049	0.7286346	-0.1827556	0.230921	-0.791420959
20133981	3.885000	0.2049	0.7270282	-0.1843620	0.232970	-0.791354105
20133981	3.895000	0.2049	0.7254186	-0.1859715	0.235020	-0.791301288
20133981	3.905000	0.2049	0.7237924	-0.1875977	0.237069	-0.791319713
20133981	3.915000	0.2049	0.7221281	-0.1892620	0.239119	-0.791497909

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
20133981	3.925000	0.2048	0.7204235	-0.1909667	0.241168	-0.791842274
20133981	3.935000	0.2047	0.7186851	-0.1927051	0.243215	-0.792322561
20133981	3.945000	0.2046	0.7169134	-0.1944767	0.245262	-0.792934254
20133981	3.955000	0.2044	0.7151165	-0.1962736	0.247307	-0.793642871
20133981	3.965000	0.2043	0.7133013	-0.1980889	0.249351	-0.794418894
20133981	3.975000	0.2041	0.7114745	-0.1999156	0.251392	-0.795234114
20133981	3.985000	0.2038	0.7096361	-0.2017541	0.253432	-0.796088912
20133981	3.995000	0.2036	0.7077912	-0.2035990	0.255469	-0.796962351
20133981	4.005000	0.2034	0.7059479	-0.2054423	0.257504	-0.797823213
20133981	4.015000	0.2031	0.7041188	-0.2072714	0.259536	-0.798623018
20133981	4.025000	0.2029	0.7023073	-0.2090829	0.261566	-0.799350165
20133981	4.035000	0.2027	0.7005051	-0.2108850	0.263594	-0.800037786
20133981	4.045000	0.2024	0.6987086	-0.2126816	0.265619	-0.800700933
20133981	4.055000	0.2022	0.6969126	-0.2144775	0.267642	-0.801359236
20133981	4.065000	0.2019	0.6951227	-0.2162675	0.269663	-0.801992618
20133981	4.075000	0.2017	0.6933445	-0.2180457	0.271681	-0.802580975
20133981	4.085000	0.2014	0.6915788	-0.2198114	0.273696	-0.803121872
20133981	4.095000	0.2012	0.6898343	-0.2215559	0.275709	-0.803585097
20133981	4.105000	0.2010	0.6881123	-0.2232778	0.277720	-0.803967178
20133981	4.115000	0.2007	0.6864068	-0.2249833	0.279729	-0.804291345
20133981	4.125000	0.2005	0.6847181	-0.2266721	0.281735	-0.804557748
20133981	4.135000	0.2003	0.6830454	-0.2283448	0.283739	-0.804769479
20133981	4.145000	0.2001	0.6813863	-0.2300038	0.285742	-0.804936469
20133981	4.155000	0.1999	0.6797419	-0.2316483	0.287742	-0.805055946
20133981	4.165000	0.1997	0.6781043	-0.2332859	0.289740	-0.805155635
20133981	4.175000	0.1995	0.6764584	-0.2349318	0.291736	-0.805288233
20133981	4.185000	0.1993	0.6748027	-0.2365875	0.293730	-0.805458106
20133981	4.195000	0.1991	0.6731345	-0.2382557	0.295722	-0.805673897
20133981	4.205000	0.1988	0.6714530	-0.2399372	0.297712	-0.805937879
20133981	4.215000	0.1986	0.6697650	-0.2416252	0.299699	-0.806226619
20133981	4.225000	0.1983	0.6680747	-0.2433155	0.301684	-0.806525692
20133981	4.235000	0.1981	0.6663846	-0.2450056	0.303666	-0.806826845
20133981	4.245000	0.1978	0.6646899	-0.2467003	0.305645	-0.807146102
20133981	4.255000	0.1976	0.6629899	-0.2484003	0.307622	-0.807485215
20133981	4.265000	0.1973	0.6612866	-0.2501036	0.309596	-0.807837568
20133981	4.275000	0.1970	0.6595704	-0.2518198	0.311568	-0.808234207
20133981	4.285000	0.1967	0.6578379	-0.2535523	0.313536	-0.808685161
20133981	4.295000	0.1964	0.6560862	-0.2553039	0.315502	-0.809198871
20133981	4.305000	0.1961	0.6543113	-0.2570789	0.317465	-0.809787668
20133981	4.315000	0.1957	0.6525070	-0.2588831	0.319424	-0.810469553
20133981	4.325000	0.1954	0.6506740	-0.2607162	0.321379	-0.811241515
20133981	4.335000	0.1950	0.6488050	-0.2625851	0.323331	-0.812124856
20133981	4.345000	0.1946	0.6469087	-0.2644815	0.325279	-0.813091733
20133981	4.355000	0.1942	0.6450001	-0.2663900	0.327222	-0.814094581
20133981	4.365000	0.1937	0.6430840	-0.2683062	0.329162	-0.815119058
20133981	4.375000	0.1933	0.6411635	-0.2702266	0.331097	-0.816155300
20133981	4.385000	0.1929	0.6392448	-0.2721454	0.333028	-0.817184784
20133981	4.395000	0.1924	0.6373401	-0.2740500	0.334955	-0.818170875
20133981	4.405000	0.1920	0.6354479	-0.2759422	0.336877	-0.819119148
20133981	4.415000	0.1916	0.6335617	-0.2778285	0.338795	-0.820049278

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
20133981	4.425000	0.1912	0.6316811	-0.2797091	0.340709	-0.820962772
20133981	4.435000	0.1907	0.6298045	-0.2815857	0.342618	-0.821864381
20133981	4.445000	0.1903	0.6279249	-0.2834652	0.344523	-0.822774820
20133981	4.455000	0.1899	0.6260371	-0.2853531	0.346424	-0.823709562
20133981	4.465000	0.1894	0.6241323	-0.2872578	0.348321	-0.824693270
20133981	4.475000	0.1890	0.6222109	-0.2891792	0.350213	-0.825724624
20133981	4.485000	0.1885	0.6202984	-0.2910917	0.352100	-0.826730371
20133981	4.495000	0.1881	0.6184029	-0.2929873	0.353983	-0.827688210
20133981	4.505000	0.1876	0.6165289	-0.2948612	0.355861	-0.828585766
20133981	4.515000	0.1872	0.6146869	-0.2967032	0.357735	-0.829394661
20133981	4.525000	0.1868	0.6128867	-0.2985035	0.359604	-0.830088831
20133981	4.535000	0.1864	0.6111363	-0.3002539	0.361470	-0.830647223
20133981	4.545000	0.1860	0.6094371	-0.3019531	0.363332	-0.831067525
20133981	4.555000	0.1856	0.6077883	-0.3036019	0.365190	-0.831353769
20133981	4.565000	0.1853	0.6061874	-0.3052027	0.367045	-0.831514195
20133981	4.575000	0.1850	0.6046268	-0.3067634	0.368896	-0.831571221
20133981	4.585000	0.1847	0.6030891	-0.3083011	0.370745	-0.831572473
20133981	4.595000	0.1844	0.6015656	-0.3098246	0.372590	-0.831542060
20133981	4.605000	0.1841	0.6000426	-0.3113475	0.374433	-0.831517071
20133981	4.615000	0.1838	0.5985163	-0.3128739	0.376273	-0.831507698
20133981	4.625000	0.1835	0.5969886	-0.3144016	0.378110	-0.831508435
20133981	4.635000	0.1832	0.5954391	-0.3159510	0.379944	-0.831572875
20133981	4.645000	0.1829	0.5938658	-0.3175243	0.381775	-0.831705616
20133981	4.655000	0.1826	0.5922662	-0.3191239	0.383603	-0.831912838
20133981	4.665000	0.1823	0.5906288	-0.3207614	0.385427	-0.832223296
20133981	4.675000	0.1819	0.5889532	-0.3224369	0.387248	-0.832636766
20133981	4.685000	0.1815	0.5872394	-0.3241508	0.389065	-0.833152704
20133981	4.695000	0.1811	0.5854862	-0.3259040	0.390879	-0.833772555
20133981	4.705000	0.1807	0.5836990	-0.3276912	0.392688	-0.834482022
20133981	4.715000	0.1803	0.5818825	-0.3295077	0.394493	-0.835268110
20133981	4.725000	0.1799	0.5800469	-0.3313432	0.396294	-0.836104326
20133981	4.735000	0.1794	0.5782033	-0.3331868	0.398091	-0.836962290
20133981	4.745000	0.1790	0.5763578	-0.3350324	0.399883	-0.837826855
20133981	4.755000	0.1785	0.5745198	-0.3368704	0.401670	-0.838674068
20133981	4.765000	0.1781	0.5727004	-0.3386898	0.403453	-0.839476869
20133981	4.775000	0.1777	0.5709042	-0.3404860	0.405232	-0.840224423
20133981	4.785000	0.1773	0.5691475	-0.3422427	0.407007	-0.840876937
20133981	4.795000	0.1769	0.5674237	-0.3439664	0.408777	-0.841451578
20133981	4.805000	0.1765	0.5657212	-0.3456690	0.410544	-0.841977723
20133981	4.815000	0.1761	0.5640349	-0.3473552	0.412307	-0.842467755
20133981	4.825000	0.1757	0.5623511	-0.3490391	0.414066	-0.842955753
20133981	4.835000	0.1753	0.5606560	-0.3507342	0.415821	-0.843474627
20133981	4.845000	0.1749	0.5589499	-0.3524403	0.417572	-0.844023325
20133981	4.855000	0.1745	0.5572276	-0.3541626	0.419319	-0.844614215
20133981	4.865000	0.1741	0.5554910	-0.3558992	0.421062	-0.845242292
20133981	4.875000	0.1737	0.5537414	-0.3576488	0.422801	-0.845904343
20133981	4.885000	0.1733	0.5519893	-0.3594009	0.424535	-0.846575104
20133981	4.895000	0.1728	0.5502424	-0.3611478	0.426266	-0.847236469
20133981	4.905000	0.1724	0.5485165	-0.3628736	0.427992	-0.847851530
20133981	4.915000	0.1720	0.5468294	-0.3645608	0.429714	-0.848379575

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
20133981	4.925000	0.1717	0.5451915	-0.3661986	0.431433	-0.848796502
20133981	4.935000	0.1713	0.5435947	-0.3677954	0.433148	-0.849122658
20133981	4.945000	0.1709	0.5420385	-0.3693516	0.434859	-0.849359773
20133981	4.955000	0.1706	0.5405214	-0.3708688	0.436567	-0.849512182
20133981	4.965000	0.1703	0.5390281	-0.3723621	0.438271	-0.849615291
20133981	4.975000	0.1700	0.5375442	-0.3738460	0.439973	-0.849702336
20133981	4.985000	0.1697	0.5360652	-0.3753249	0.441671	-0.849783637
20133981	4.995000	0.1693	0.5345645	-0.3768257	0.443366	-0.849919446
20133981	5.005000	0.1690	0.5330206	-0.3783696	0.445058	-0.850157298
20133981	5.015000	0.1687	0.5314274	-0.3799628	0.446747	-0.850510322
20133981	5.025000	0.1683	0.5297739	-0.3816163	0.448432	-0.851001896
20133981	5.035000	0.1679	0.5280335	-0.3833567	0.450113	-0.851689965
20133981	5.045000	0.1675	0.5261967	-0.3851934	0.451790	-0.852594130
20133981	5.055000	0.1670	0.5242501	-0.3871401	0.453462	-0.853742421
20133981	5.065000	0.1665	0.5221869	-0.3892032	0.455130	-0.855147526
20133981	5.075000	0.1660	0.5200094	-0.3913808	0.456792	-0.856802896
20133981	5.085000	0.1654	0.5177318	-0.3936583	0.458449	-0.858675048
20133981	5.095000	0.1648	0.5153844	-0.3960058	0.460099	-0.860696942
20133981	5.105000	0.1641	0.5129881	-0.3984021	0.461743	-0.862821765
20133981	5.115000	0.1635	0.5105912	-0.4007990	0.463381	-0.864944562
20133981	5.125000	0.1629	0.5082154	-0.4031748	0.465013	-0.867018782
20133981	5.135000	0.1623	0.5058677	-0.4055225	0.466638	-0.869029716
20133981	5.145000	0.1616	0.5035675	-0.4078227	0.468258	-0.870936595
20133981	5.155000	0.1611	0.5013517	-0.4100384	0.469871	-0.872661486
20133981	5.165000	0.1605	0.4992140	-0.4121762	0.471479	-0.874219343
20133981	5.175000	0.1600	0.4971379	-0.4142523	0.473082	-0.875646226
20133981	5.185000	0.1595	0.4950999	-0.4162902	0.474679	-0.876992807
20133981	5.195000	0.1590	0.4930745	-0.4183157	0.476271	-0.878313579
20133981	5.205000	0.1585	0.4910506	-0.4203396	0.477859	-0.879631653
20133981	5.215000	0.1580	0.4890204	-0.4223698	0.479441	-0.880963542
20133981	5.225000	0.1574	0.4869853	-0.4244049	0.481018	-0.882306330
20133981	5.235000	0.1569	0.4849702	-0.4264199	0.482589	-0.883608073
20133981	5.245000	0.1564	0.4829805	-0.4284096	0.484156	-0.884858102
20133981	5.255000	0.1560	0.4810342	-0.4303560	0.485718	-0.886019647
20133981	5.265000	0.1555	0.4791270	-0.4322631	0.487276	-0.887102030
20133981	5.275000	0.1550	0.4772609	-0.4341293	0.488828	-0.888102047
20133981	5.285000	0.1546	0.4754583	-0.4359319	0.490376	-0.888974130
20133981	5.295000	0.1542	0.4737354	-0.4376547	0.491920	-0.889686249
20133981	5.305000	0.1538	0.4720804	-0.4393098	0.493460	-0.890263706
20133981	5.315000	0.1534	0.4704807	-0.4409095	0.494996	-0.890732668
20133981	5.325000	0.1531	0.4689106	-0.4424795	0.496529	-0.891145676
20133981	5.335000	0.1527	0.4673692	-0.4440210	0.498058	-0.891505137
20133981	5.345000	0.1524	0.4658489	-0.4455412	0.499583	-0.891826309
20133981	5.355000	0.1520	0.4643456	-0.4470445	0.501105	-0.892117694
20133981	5.365000	0.1517	0.4628552	-0.4485350	0.502623	-0.892387830
20133981	5.375000	0.1513	0.4613698	-0.4500203	0.504139	-0.892651938
20133981	5.385000	0.1510	0.4598571	-0.4515331	0.505651	-0.892974593
20133981	5.395000	0.1507	0.4583000	-0.4530902	0.507159	-0.893388703
20133981	5.405000	0.1503	0.4566800	-0.4547101	0.508664	-0.893930219
20133981	5.415000	0.1499	0.4549719	-0.4564182	0.510165	-0.894647926

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
20133981	5.425000	0.1495	0.4531794	-0.4582107	0.511662	-0.895533361
20133981	5.435000	0.1491	0.4513021	-0.4600880	0.513155	-0.896586180
20133981	5.445000	0.1486	0.4493311	-0.4620591	0.514644	-0.897822902
20133981	5.455000	0.1482	0.4472651	-0.4641251	0.516128	-0.899244614
20133981	5.465000	0.1477	0.4451344	-0.4662557	0.517607	-0.900791645
20133981	5.475000	0.1471	0.4429631	-0.4684271	0.519080	-0.902417131
20133981	5.485000	0.1466	0.4407699	-0.4706202	0.520549	-0.904084101
20133981	5.495000	0.1461	0.4385956	-0.4727946	0.522013	-0.905714579
20133981	5.505000	0.1456	0.4364635	-0.4749267	0.523471	-0.907263979
20133981	5.515000	0.1451	0.4343885	-0.4770017	0.524925	-0.908704638
20133981	5.525000	0.1447	0.4323812	-0.4790089	0.526374	-0.910016693
20133981	5.535000	0.1442	0.4304517	-0.4809384	0.527818	-0.911182158
20133981	5.545000	0.1438	0.4285966	-0.4827936	0.529258	-0.912208222
20133981	5.555000	0.1434	0.4268156	-0.4845746	0.530694	-0.913096264
20133981	5.565000	0.1430	0.4251010	-0.4862892	0.532126	-0.913861439
20133981	5.575000	0.1426	0.4234338	-0.4879564	0.533554	-0.914540179
20133981	5.585000	0.1422	0.4217568	-0.4896334	0.534978	-0.915239982
20133981	5.595000	0.1419	0.4200498	-0.4913404	0.536399	-0.915998586
20133981	5.605000	0.1415	0.4182995	-0.4930906	0.537815	-0.916840136
20133981	5.615000	0.1411	0.4164882	-0.4949020	0.539228	-0.917797469
20133981	5.625000	0.1406	0.4146229	-0.4967672	0.540636	-0.918856502
20133981	5.635000	0.1402	0.4127231	-0.4986670	0.542041	-0.919980921
20133981	5.645000	0.1398	0.4107940	-0.5005961	0.543441	-0.921160623
20133981	5.655000	0.1394	0.4088466	-0.5025436	0.544836	-0.922375217
20133981	5.665000	0.1389	0.4068945	-0.5044957	0.546228	-0.923599422
20133981	5.675000	0.1385	0.4049451	-0.5064451	0.547615	-0.924819730
20133981	5.685000	0.1381	0.4030035	-0.5083867	0.548998	-0.926026836
20133981	5.695000	0.1376	0.4010654	-0.5103247	0.550376	-0.927228555
20133981	5.705000	0.1372	0.3991282	-0.5122619	0.551751	-0.928429931
20133981	5.715000	0.1368	0.3971825	-0.5142077	0.553121	-0.929647900
20133981	5.725000	0.1364	0.3951928	-0.5161974	0.554487	-0.930946358
20133981	5.735000	0.1359	0.3931521	-0.5182381	0.555848	-0.932337701
20133981	5.745000	0.1355	0.3910556	-0.5203346	0.557205	-0.933829889
20133981	5.755000	0.1350	0.3889443	-0.5224459	0.558557	-0.935348958
20133981	5.765000	0.1345	0.3868200	-0.5245702	0.559905	-0.936891593
20133981	5.775000	0.1341	0.3846915	-0.5266987	0.561248	-0.938441984
20133981	5.785000	0.1336	0.3825653	-0.5288249	0.562586	-0.939988628
20133981	5.795000	0.1332	0.3804672	-0.5309229	0.563920	-0.941485614
20133981	5.805000	0.1327	0.3784153	-0.5329748	0.565250	-0.942901351
20133981	5.815000	0.1323	0.3764154	-0.5349748	0.566575	-0.944225997
20133981	5.825000	0.1319	0.3744765	-0.5369137	0.567896	-0.945443988
20133981	5.835000	0.1315	0.3725987	-0.5387915	0.569213	-0.946555831
20133981	5.845000	0.1311	0.3708165	-0.5405736	0.570526	-0.947501220
20133981	5.855000	0.1307	0.3690959	-0.5422943	0.571835	-0.948340856
20133981	5.865000	0.1304	0.3673984	-0.5439918	0.573140	-0.949142195
20133981	5.875000	0.1300	0.3656818	-0.5457083	0.574442	-0.949979141
20133981	5.885000	0.1296	0.3639391	-0.5474511	0.575741	-0.950863712
20133981	5.895000	0.1293	0.3621783	-0.5492118	0.577036	-0.951781631
20133981	5.905000	0.1289	0.3603397	-0.5510505	0.578326	-0.952836372
20133981	5.915000	0.1285	0.3584272	-0.5529630	0.579613	-0.954020359

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
20133981	5.925000	0.1281	0.3564577	-0.5549324	0.580896	-0.955303855
20133981	5.935000	0.1277	0.3544929	-0.5568973	0.582175	-0.956580497
20133981	5.945000	0.1273	0.3525618	-0.5588283	0.583450	-0.957800157
20133981	5.955000	0.1269	0.3506956	-0.5606946	0.584721	-0.958910152
20133981	5.965000	0.1265	0.3489427	-0.5624475	0.585988	-0.959828041
20133981	5.975000	0.1262	0.3473290	-0.5640612	0.587251	-0.960510470
20133981	5.985000	0.1259	0.3458666	-0.5655236	0.588512	-0.960938051
20133981	5.995000	0.1256	0.3444871	-0.5669031	0.589770	-0.961227976
20133981	6.005000	0.1253	0.3431660	-0.5682241	0.591024	-0.961422458
20133981	6.015000	0.1251	0.3418721	-0.5695181	0.592276	-0.961574756
20133981	6.025000	0.1248	0.3405927	-0.5707975	0.593526	-0.961706229
20133981	6.035000	0.1245	0.3393043	-0.5720858	0.594773	-0.961856514
20133981	6.045000	0.1243	0.3379514	-0.5734387	0.596017	-0.962118819
20133981	6.055000	0.1240	0.3365400	-0.5748502	0.597258	-0.962482713
20133981	6.065000	0.1237	0.3350656	-0.5763245	0.598496	-0.962954819
20133981	6.075000	0.1234	0.3335577	-0.5778324	0.599731	-0.963485688
20133981	6.085000	0.1231	0.3320183	-0.5793719	0.600963	-0.964071803
20133981	6.095000	0.1228	0.3304604	-0.5809298	0.602193	-0.964690961
20133981	6.105000	0.1225	0.3288976	-0.5824926	0.603419	-0.965320662
20133981	6.115000	0.1221	0.3273282	-0.5840619	0.604642	-0.965963453
20133981	6.125000	0.1218	0.3257126	-0.5856776	0.605862	-0.966685146
20133981	6.135000	0.1215	0.3240211	-0.5873690	0.607079	-0.967533916
20133981	6.145000	0.1212	0.3222656	-0.5891245	0.608292	-0.968489915
20133981	6.155000	0.1208	0.3204543	-0.5909359	0.609502	-0.969539262
20133981	6.165000	0.1205	0.3186149	-0.5927753	0.610708	-0.970636055
20133981	6.175000	0.1201	0.3167493	-0.5946408	0.611911	-0.971776858
20133981	6.185000	0.1197	0.3148546	-0.5965356	0.613110	-0.972966582
20133981	6.195000	0.1194	0.3129582	-0.5984320	0.614306	-0.974160068
20133981	6.205000	0.1190	0.3110870	-0.6003032	0.615497	-0.975313865
20133981	6.215000	0.1187	0.3092986	-0.6020916	0.616686	-0.976334415
20133981	6.225000	0.1184	0.3076277	-0.6037625	0.617871	-0.977166079
20133981	6.235000	0.1180	0.3060779	-0.6053123	0.619053	-0.977803849
20133981	6.245000	0.1178	0.3046474	-0.6067428	0.620232	-0.978251271
20133981	6.255000	0.1175	0.3033260	-0.6080641	0.621408	-0.978525683
20133981	6.265000	0.1173	0.3020532	-0.6093370	0.622582	-0.978725158
20133981	6.275000	0.1170	0.3008241	-0.6105661	0.623754	-0.978857689
20133981	6.285000	0.1168	0.2996129	-0.6117772	0.624923	-0.978964642
20133981	6.295000	0.1165	0.2983986	-0.6129915	0.626089	-0.979080014
20133981	6.305000	0.1163	0.2971631	-0.6142271	0.627254	-0.979232460
20133981	6.315000	0.1160	0.2958267	-0.6155635	0.628415	-0.979548827
20133981	6.325000	0.1158	0.2943708	-0.6170194	0.629574	-0.980057850
20133981	6.335000	0.1155	0.2928205	-0.6185697	0.630731	-0.980719149
20133981	6.345000	0.1152	0.2912003	-0.6201899	0.631884	-0.981493227
20133981	6.355000	0.1149	0.2895351	-0.6218551	0.633034	-0.982340135
20133981	6.365000	0.1146	0.2878251	-0.6235650	0.634182	-0.983259171
20133981	6.375000	0.1143	0.2860168	-0.6253734	0.635326	-0.984334737
20133981	6.385000	0.1139	0.2841360	-0.6272542	0.636467	-0.985525332
20133981	6.395000	0.1136	0.2821863	-0.6292039	0.637604	-0.986825004
20133981	6.405000	0.1132	0.2801490	-0.6312411	0.638738	-0.988262475
20133981	6.415000	0.1129	0.2780201	-0.6333700	0.639869	-0.989843599

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
20133981	6.425000	0.1125	0.2757573	-0.6356329	0.640995	-0.991633989
20133981	6.435000	0.1121	0.2733397	-0.6380504	0.642118	-0.993665293
20133981	6.445000	0.1116	0.2707398	-0.6406504	0.643236	-0.995979555
20133981	6.455000	0.1111	0.2679226	-0.6434676	0.644350	-0.998630114
20133981	6.465000	0.1107	0.2649167	-0.6464734	0.645459	-1.001571313
20133981	6.475000	0.1101	0.2617789	-0.6496112	0.646563	-1.004714340
20133981	6.485000	0.1096	0.2585394	-0.6528508	0.647662	-1.008011878
20133981	6.495000	0.1091	0.2552213	-0.6561688	0.648755	-1.011427596
20133981	6.505000	0.1085	0.2518418	-0.6595483	0.649843	-1.014934823
20133981	6.515000	0.1080	0.2484120	-0.6629782	0.650925	-1.018516257
20133981	6.525000	0.1074	0.2450393	-0.6663509	0.652002	-1.022006676
20133981	6.535000	0.1069	0.2417608	-0.6696293	0.653074	-1.025349528
20133981	6.545000	0.1064	0.2385866	-0.6728036	0.654141	-1.028530240
20133981	6.555000	0.1059	0.2355023	-0.6758879	0.655202	-1.031571150
20133981	6.565000	0.1054	0.2324957	-0.6788945	0.656259	-1.034491330
20133981	6.575000	0.1050	0.2295408	-0.6818493	0.657311	-1.037330940
20133981	6.585000	0.1045	0.2266017	-0.6847884	0.658359	-1.040144831
20133981	6.595000	0.1040	0.2236445	-0.6877457	0.659401	-1.042984724
20133981	6.605000	0.1036	0.2206447	-0.6907455	0.660440	-1.045887440
20133981	6.615000	0.1031	0.2175958	-0.6937944	0.661473	-1.048862785
20133981	6.625000	0.1026	0.2144898	-0.6969004	0.662502	-1.051922575
20133981	6.635000	0.1021	0.2113333	-0.7000568	0.663525	-1.055056572
20133981	6.645000	0.1017	0.2081374	-0.7032528	0.664544	-1.058248058
20133981	6.655000	0.1012	0.2049259	-0.7064643	0.665559	-1.061460808
20133981	6.665000	0.1007	0.2017374	-0.7096528	0.666568	-1.064636886
20133981	6.675000	0.1002	0.1986333	-0.7127568	0.667573	-1.067684457
20133981	6.685000	0.0998	0.1956193	-0.7157709	0.668573	-1.070595428
20133981	6.695000	0.0994	0.1926901	-0.7187001	0.669568	-1.073378101
20133981	6.705000	0.0989	0.1898345	-0.7215556	0.670560	-1.076049581
20133981	6.715000	0.0985	0.1870156	-0.7243745	0.671547	-1.078665391
20133981	6.725000	0.0981	0.1842046	-0.7271856	0.672530	-1.081268534
20133981	6.735000	0.0977	0.1813745	-0.7300157	0.673509	-1.083899185
20133981	6.745000	0.0973	0.1785040	-0.7328862	0.674483	-1.086588785
20133981	6.755000	0.0968	0.1755825	-0.7358077	0.675454	-1.089352891
20133981	6.765000	0.0964	0.1726165	-0.7387737	0.676420	-1.092181817
20133981	6.775000	0.0960	0.1696506	-0.7417396	0.677382	-1.095009461
20133981	6.785000	0.0956	0.1666804	-0.7447097	0.678340	-1.097842127
20133981	6.795000	0.0951	0.1637146	-0.7476755	0.679293	-1.100667253
20133981	6.805000	0.0947	0.1607786	-0.7506116	0.680242	-1.103447512
20133981	6.815000	0.0943	0.1579492	-0.7534410	0.681187	-1.106070086
20133981	6.825000	0.0939	0.1552351	-0.7561551	0.682129	-1.108522698
20133981	6.835000	0.0936	0.1526133	-0.7587768	0.683066	-1.110839590
20133981	6.845000	0.0932	0.1500721	-0.7613180	0.684000	-1.113038331
20133981	6.855000	0.0928	0.1476081	-0.7637821	0.684930	-1.115124300
20133981	6.865000	0.0925	0.1452260	-0.7661641	0.685857	-1.117090821
20133981	6.875000	0.0922	0.1429542	-0.7684360	0.686780	-1.118897036
20133981	6.885000	0.0918	0.1407841	-0.7706061	0.687700	-1.120555833
20133981	6.895000	0.0915	0.1387212	-0.7726689	0.688617	-1.122059435
20133981	6.905000	0.0912	0.1367837	-0.7746065	0.689531	-1.123382241
20133981	6.915000	0.0910	0.1350035	-0.7763867	0.690442	-1.124478266

REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNEL 0

RECORD NO.	TIME	POWER	REACTIVITY	COMP. REACT.	ENERGY	B(T)
20133981	6.925000	0.0907	0.1333441	-0.7780460	0.691350	-1.125400886
20133981	6.935000	0.0905	0.1318141	-0.7795760	0.692256	-1.126138404
20133981	6.945000	0.0902	0.1304235	-0.7809667	0.693159	-1.126676708
20133981	6.955000	0.0900	0.1291836	-0.7822066	0.694061	-1.127000019
20133981	6.965000	0.0898	0.1280718	-0.7833183	0.694960	-1.127141401
20133981	6.975000	0.0896	0.1269866	-0.7844036	0.695857	-1.127247483
20133981	6.985000	0.0894	0.1259115	-0.7854786	0.696753	-1.127341792
20133981	6.995000	0.0892	0.1248348	-0.7865553	0.697646	-1.127441332
20133981	7.005000	0.0891	0.1237485	-0.7876417	0.698538	-1.127557516
20133981	7.015000	0.0889	0.1226475	-0.7887427	0.699428	-1.127697378
20133981	7.025000	0.0887	0.1214596	-0.7899305	0.700315	-1.127964050
20133981	7.035000	0.0885	0.1201900	-0.7912002	0.701201	-1.128349990
20133981	7.045000	0.0883	0.1188458	-0.7925443	0.702085	-1.128844440
20133981	7.055000	0.0880	0.1174340	-0.7939562	0.702966	-1.129437402
20133981	7.065000	0.0878	0.1159522	-0.7954380	0.703845	-1.130131826
20133981	7.075000	0.0876	0.1144246	-0.7969655	0.704722	-1.130893037
20133981	7.085000	0.0874	0.1128635	-0.7985266	0.705597	-1.131703615
20133981	7.095000	0.0871	0.1112750	-0.8001152	0.706469	-1.132554680
20133981	7.105000	0.0869	0.1096542	-0.8017360	0.707339	-1.133453041
20133981	7.115000	0.0866	0.1079789	-0.8034113	0.708207	-1.134429976
20133981	7.125000	0.0864	0.1062924	-0.8050977	0.709072	-1.135424033
20133981	7.135000	0.0862	0.1045879	-0.8068023	0.709935	-1.136445016
20133981	7.145000	0.0859	0.1028754	-0.8085148	0.710796	-1.137478635
20133981	7.155000	0.0857	0.1011608	-0.8102294	0.711654	-1.138516545
20133981	7.165000	0.0854	0.0994373	-0.8119529	0.712509	-1.139568314
20133981	7.175000	0.0852	0.0977462	-0.8136440	0.713362	-1.140575930
20133981	7.185000	0.0850	0.0961007	-0.8152895	0.714213	-1.141521066
20133981	7.195000	0.0847	0.0945068	-0.8168833	0.715062	-1.142395347
20133981	7.205000	0.0845	0.0929628	-0.8184274	0.715908	-1.143201634
20133981	7.215000	0.0843	0.0915783	-0.8198119	0.716752	-1.143786609
20133981	7.225000	0.0841	0.0901943	-0.8211959	0.717595	-1.144372970
20133981	7.235000	0.0839	0.0888133	-0.8225768	0.718435	-1.144956887
20133981	7.245000	0.0837	0.0874391	-0.8239511	0.719273	-1.145533428
20133981	7.255000	0.0835	0.0860610	-0.8253291	0.720109	-1.146117136
20133981	7.265000	0.0833	0.0846735	-0.8267167	0.720943	-1.146715969

CALCULATIONS REQUIRED 0 MIN 28.1 SEC

TOTAL PROBLEM TIME WAS 1 MIN 38.5 SEC

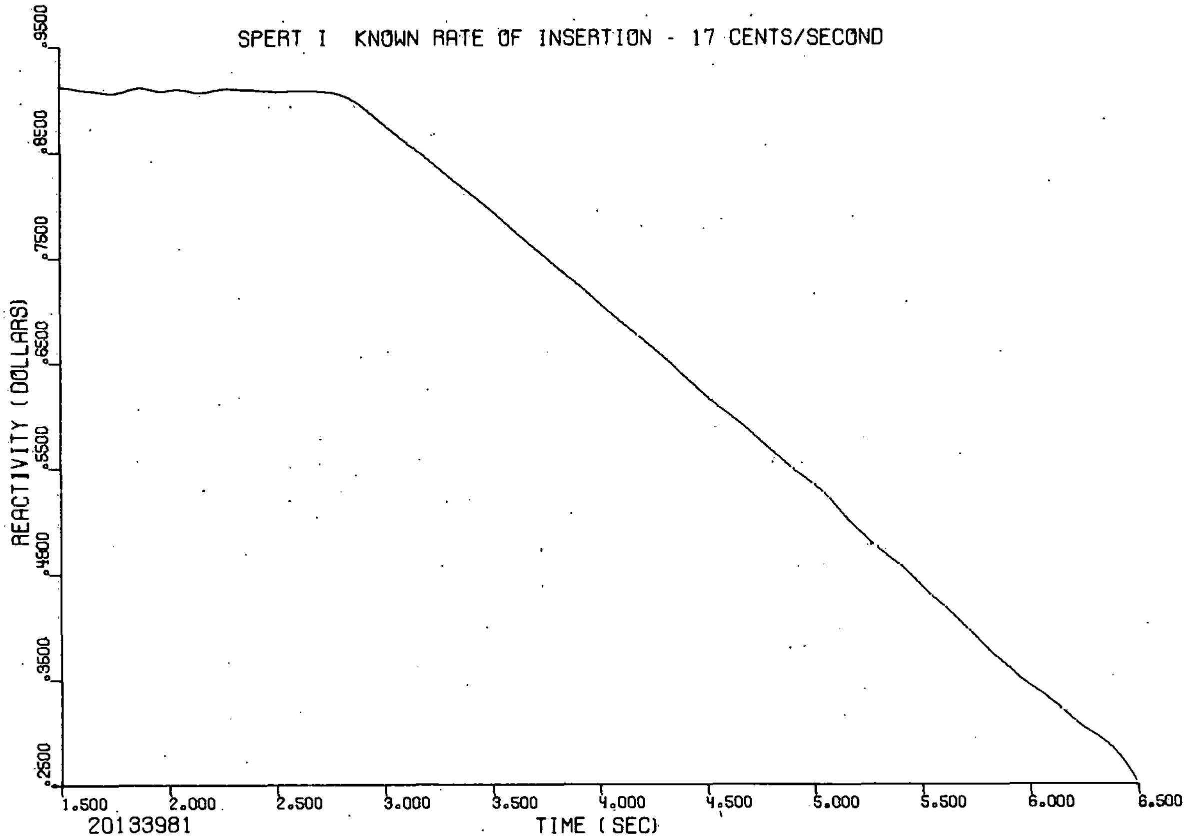

Fig. 30 REACTIVITY calculations on power data with a known rate of compensated reactivity insertion.

4. CHECKOUT OF FREQUENCY RESPONSE

Because of the nature of the calculations made in the FREQUENCY RESPONSE program, a rather detailed error analysis and checkout was necessary. This analysis is presented in Section II, page 3.

VII. OPERATING TIME

In this section, some estimates are given of the time required to select, prepare and process SPORT input data.

1. DATA SELECTION AND CONVERSION

The time required for BCD-to-binary conversion and normalization of one Spert 1-3 data card is on the order of 200 milliseconds. The time required to prepare other types of card data is generally less. Type 5 or "tape" data is already in binary form. However, approximately 300 milliseconds (729 tape drive) are required for each data record that must be passed over in order to reach the first data record used in the problem.

2. THE SMOOTH PROGRAM

Approximately 50 milliseconds per output point are required to smooth even time increment data on 25 points and obtain an output listing. Smoothing the same data on 99 points would require about 95 milliseconds per output point. A time saving of about 50 percent may be realized by deleting the output listing. Smoothing data separated by unequal time increments requires that an additional 10 to 30 percent be added to the estimates given above.

3. THE REACTIVITY PROGRAM

REACTIVITY calculations using 6 delayed neutron groups require about 50 milliseconds per point. Fifteen-group calculations require about 55 milliseconds per point.

4. THE FREQUENCY RESPONSE PROGRAM

FREQUENCY RESPONSE calculations require about 3 milliseconds per input point per frequency. In other words, a transient response of 2000 points may be analyzed at 100 separate frequencies in approximately 10 minutes.

5. PLOTS

Approximately 10 to 15 seconds of computer time are required to generate a standard-size 10- by 7-inch plot. Increasing the size of the plot to 30 by 26 inches nearly doubles the required computer time. CALCOMP plotter time for a 10- by 7-inch plot is about 2 minutes and for a 30- by 26-inch plot is about 10 minutes.

VIII. REFERENCES

1. F. Schroeder (ed.), Quarterly Technical Report Spert Project, April, May, June, 1962, IDO-16806 (September 1962) pp 29-30.

2. F. Schroeder (ed.), Quarterly Technical Report Spert Project, July, August, September, 1962, IDO-16829 (February 1963) pp 27-28.

3. F. Schroeder (ed.), Quarterly Technical Report Spert Project, January, February, March, 1962, IDO-16788 (August 1962) pp 14-15.

4. C. R. Wylie, Jr., Advance Engineering Mathematics, 2d ed. New York: McGraw-Hill Publishing Co., 1960.

5. R. V. Churchill, Complex Variables and Applications. New York: McGraw-Hill Publishing Co., 1948.

3

APPENDIX A -- PROOF OF THEOREMS USED IN SECTION II

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APPENDIX A -- PROOF OF THEOREMS USED IN SECTION II

THEOREM I: If $f(t)$ is a real-valued function such that $f(t) = f(t_n - t)$ for $0 \leq t \leq t_n$ and zero elsewhere and if

$$F(\omega) = \int_0^\infty f(t)\, e^{-i\omega t}\, dt \quad , \tag{A-1}$$

then, for $\omega = \frac{(2m-1)\pi}{t_n}$ (m an integer), the real part of $F(\omega)$ is zero; and for $\omega = \frac{2m\pi}{t_n}$, the imaginary part of $F(\omega)$ is zero.

Proof: Since $f(t) = 0$ for $t > t_n$,

$$F(\omega) = \int_0^\infty f(t)\, e^{-i\omega t}\, dt = \int_0^{t_n} f(t)\, e^{-i\omega t}\, dt \quad . \tag{A-2}$$

Furthermore, if $f(t) = f(t_n - t)$ for $0 \leq t \leq t_n$,

$$F(\omega) = \int_0^{\frac{1}{2}t_n} f(t)\, e^{-i\omega t}\, dt + \int_{\frac{1}{2}t_n}^{t_n} f(t_n - t)\, e^{-i\omega t}\, dt \tag{A-3}$$

and with the change of variables $t' = t_n - t$,

$$F(\omega) = \int_0^{\frac{1}{2}t_n} f(t)\, e^{-i\omega t}\, dt + e^{-i\omega t_n} \int_0^{\frac{1}{2}t_n} f(t')\, e^{i\omega t'}\, dt' \quad . \tag{A-4}$$

Now if

$$G(\omega) = \int_0^{\frac{1}{2}t_n} f(t)\, e^{-i\omega t}\, dt \quad , \tag{A-5}$$

Equation (A-4) may be written as

$$F(\omega) = G(\omega) + e^{-i\omega t_n}\, \overline{G(\omega)} \tag{A-6}$$

where $\overline{G(\omega)}$ is the complex conjugate of $G(\omega)$.

Now if $\omega = (2m-1)\pi/t_n$,

$$e^{-i\omega t_n} = -1 \tag{A-7}$$

and

$$F(\omega) = 2\ i\ \text{Imag}\ [G(\omega)] \quad . \tag{A-8}$$

Consequently, the real part of $F(\omega)$ is zero.

Similarly, if $\omega = 2m\pi/t_n$,

$$e^{-i\omega t_n} = 1 \tag{A-9}$$

and

$$F(\omega) = 2\ \text{Real}\ [G(\omega)] \tag{A-10}$$

and the imaginary part of $F(\omega)$ is zero.

Lemma I: If $F(\omega)$ and $F^*(\omega)$ are complex functions with phase angles ϕ and ϕ^*, respectively, then

$$|\sin(\phi - \phi^*)| \leq \frac{|F(\omega) - F^*(\omega)|}{|F^*(\omega)|} \quad . \tag{A-11}$$

Proof: Let $F(\omega) = F = R + i\,I$ and $F^*(\omega) = F^* = R^* + i\,I^*$.

$$\frac{|F - F^*|}{|F^*|} = \frac{\left\{(R - R^*)^2 + (I - I^*)^2\right\}^{\frac{1}{2}}}{|F^*|} \tag{A-12}$$

$$= \frac{|F| \left\{|F|^2 + (R^{*2} + I^{*2}) - 2(RR^* + II^*)\right\}^{\frac{1}{2}}}{|F|\ |F^*|} \tag{A-13}$$

$$= \frac{\left\{|F|^4 - 2(R^2 + I^2)(RR^* + II^*) + (RR^* + II^*)^2 - (RR^* + II^*)^2\right.}{|F|\ |F^*|}$$

$$+ \frac{\left.(R^2 + I^2)(R^{*2} + I^{*2})\right\}^{\frac{1}{2}}}{|F|\ |F^*|} \tag{A-14}$$

$$= \frac{\left\{[\,|F|^2 - (RR^* + II^*)]^2 + R^2 I^{*2} - 2RR^*II^* + R^{*2}I^2\right\}^{\frac{1}{2}}}{|F|\ |F^*|} \tag{A-15}$$

$$= \frac{\left\{[\,|F|^2 - (RR^* + II^*)]^2 + (R^*I - I^*R)^2\right\}^{\frac{1}{2}}}{|F|\ |F^*|} \tag{A-16}$$

$$\geq \frac{|IR^* - RI^*|}{|F|\ |F^*|} = |\sin(\phi - \phi^*)| \quad . \tag{A-17}$$

THEOREM II: Let

$$F(\omega) = \int_0^\infty f(t)\ e^{-i\omega t}\ dt \quad . \tag{A-18}$$

If

$$f^*(t) = f(t) \text{ for } 0 \leq t \leq t_n \tag{A-19}$$

and

$$f^*(t) = f(t_n) \text{ for } t > t_n \tag{A-20}$$

then

$$F(\omega) - F^*(\omega) = \int_{t_n}^{\infty} [f(t) - f(t_n)]\, e^{-i\omega t}\, dt \quad . \tag{A-21}$$

Proof:

$$F(\omega) - F^*(\omega) = \int_{o}^{\infty} f(t)\, e^{-i\omega t}\, dt - \int_{o}^{t_n} f(t)\, e^{-i\omega t}\, dt$$

$$- \int_{t_n}^{\infty} f(t_n)\, e^{-i\omega t}\, dt \tag{A-22}$$

$$= \int_{t_n}^{\infty} f(t)\, e^{-i\omega t}\, dt - \int_{t_n}^{\infty} f(t_n)\, e^{-i\omega t}\, dt \tag{A-23}$$

$$= \int_{t_n}^{\infty} [f(t) - f(t_n)]\, e^{-i\omega t}\, dt \quad . \tag{A-24}$$

Corollary 1:

$$|F(\omega) - F^*(\omega)| \leq \int_{t_n}^{\infty} |f(t) - f(t_n)|\, dt \quad . \tag{A-25}$$

Proof:

$$|F(\omega) - F^*(\omega)| = \left| \int_{t_n}^{\infty} [f(t) - f(t_n)]\, e^{-i\omega t}\, dt \right|$$

$$\leq \int_{t_n}^{\infty} |f(t) - f(t_n)|\, |e^{-i\omega t}|\, dt \tag{A-26}$$

$$= \int_{t_n}^{\infty} |f(t) - f(t_n)|\, dt \quad . \tag{A-27}$$

(Proof of the inequality is given in standard texts [5].)

Corollary 2: If $\phi(\omega)$ and $\phi^*(\omega)$ are the phase angles of $F(\omega)$ and $F^*(\omega)$, respectively, then

$$|\sin(\phi - \phi^*)| \leq \frac{\int_{t_n}^{\infty} |f(t) - f(t_n)|\ dt}{|F^*(\omega)|} . \tag{A-28}$$

Proof: This is an obvious result of Lemma 1 and Corollary 1.

Corollary 3: If, for $t \geq t_n$,

$$f(t) = \frac{f(t_n) - f(\infty)}{m} \sum_{\kappa} e^{-\alpha_\kappa (t-t_n)} + f(\infty)$$

then

$$|F(\omega) - F^*(\omega)| = \frac{|f(t_n) - f(\infty)|}{m} \left[\left(\sum_{\kappa} \frac{\alpha_\kappa}{\alpha_\kappa^2 + \omega^2} \right)^2 + \left(\frac{m}{\omega} - \sum_{\kappa} \frac{\omega}{\alpha_\kappa^2 + \omega^2} \right)^2 \right]^{\frac{1}{2}} \tag{A-29}$$

Proof:

$$|F - F^*| = \left| \int_{t_n}^{\infty} \left[\frac{f(t_n) - f(\infty)}{m} \sum_{\kappa} e^{-\alpha_\kappa (t-t_n)} + f(\infty) - f(t_n) \right] e^{-st}\ dt \right| \tag{A-30}$$

$$= \left| \frac{f(t_n) - f(\infty)}{m} \sum_{\kappa} e^{\alpha_\kappa t_n} \int_{t_n}^{\infty} e^{-(\alpha_\kappa + s)t}\ dt + \frac{f(\infty) - f(t_n)}{s} e^{-st_n} \right| \tag{A-31}$$

$$= \left| \frac{f(t_n) - f(\infty)}{m} \sum_{\kappa} \frac{1}{\alpha_\kappa + s} e^{-st_n} - \frac{f(t_n) - f(\infty)}{s} e^{-st_n} \right| \tag{A-32}$$

$$|F(\omega) - F^*(\omega)| = \left| \frac{f(t_n) - f(\infty)}{m} \sum_{\kappa} \frac{1}{\alpha_\kappa + i\omega} - \frac{f(t_n) - f(\infty)}{i\omega} \right| \tag{A-33}$$

$$= |f(t_n) - f(\infty)| \left| \frac{1}{m} \sum_{\kappa} \frac{1}{\alpha_\kappa + i\omega} + \frac{i}{\omega} \right| \tag{A-34}$$

$$= \frac{|f(t_n) - f(\infty)|}{m} \left| \sum_{\kappa} \frac{\alpha_\kappa}{\alpha_\kappa^2 + \omega^2} + i \left(\frac{m}{\omega} - \sum_{\kappa} \frac{\omega}{\alpha_\kappa^2 + \omega^2} \right) \right| \tag{A-35}$$

<u>THEOREM III:</u> Let

$$F(\omega) = \int_0^{t_n} f(t)\, e^{-i\omega t}\, dt \qquad \text{(A-36)}$$

and suppose

$$|f(t) - f^*(t)| \leq \epsilon \text{ for } 0 \leq t \leq t_n \quad . \qquad \text{(A-37)}$$

If

$$\frac{\epsilon t_n}{|F^*(\omega)|} \leq k \ , \qquad \text{(A-38)}$$

then

$$\frac{|F(\omega) - F^*(\omega)|}{|F^*(\omega)|} \leq k \quad . \qquad \text{(A-39)}$$

<u>Proof</u>: From Corollary 1 to Theorem II,

$$|F(\omega) - F^*(\omega)| \leq \int_0^{t_n} |f(t) - f^*(t)|\, dt \leq \epsilon t_n \quad . \qquad \text{(A-40)}$$

Therefore,

$$\frac{|F(\omega) - F^*(\omega)|}{|F^*(\omega)|} \leq \frac{\epsilon t_n}{|F^*(\omega)|} \leq k \quad . \qquad \text{(A-41)}$$

<u>THEOREM IV:</u> Let

$$F(\omega) = \int_0^{t_n} f(t)\, e^{-i\omega t}\, dt \qquad \text{(A-42)}$$

and let $\phi(\omega)$ be the phase angle of $F(\omega)$. Suppose $f(t) - f^*(t) \leq \epsilon$ for $0 \leq t \leq t_n$. If

$$\frac{\epsilon t_n}{|F^*|} \leq k \ , \qquad \text{(A-43)}$$

then

$$|\sin\,(\phi - \phi^*)| \leq k \quad . \qquad \text{(A-44)}$$

<u>Proof</u>: From Lemma I,

$$|\sin\,(\phi - \phi^*)| \leq \frac{|F - F^*|}{|F^*|} \qquad \text{(A-45)}$$

and from Theorem III,

$$\frac{|F - F^*|}{|F^*|} \leq \frac{\epsilon t_n}{|F^*|} \quad . \qquad \text{(A-46)}$$

Therefore,

$$|\sin\,(\phi - \phi^*)| \leq \frac{\epsilon t_n}{|F^*|} \leq k \quad . \qquad \text{(A-47)}$$

THEOREM V: Let

$$F(\omega) = \int_o^{t_n} f(t)\, e^{-i\omega t}\, dt \quad . \tag{A-48}$$

Suppose that $f(0) = f^*(0)$ and $f(t_n) = f^*(t_n)$ and suppose that on $(0, t_n)$, the i^{th} derivatives of $f(t)$ and $f^*(t)$ are continuous for all $i < m$ and that the m^{th} derivatives are sectionally continuous. If

$$\frac{d^m}{dt^m}[f(t) - f^*(t)] \leq \epsilon_m \text{ on } (0, t_n) \tag{A-49}$$

then

$$\frac{\big||F(\omega)| - |F^*(\omega)|\big|}{|F^*(\omega)|} \leq \sum_{j=1}^{m-1} \frac{1}{\omega^{j+1}\ |F^*(\omega)|} \left| \frac{d^j}{dt^j} [f(t) - f^*(t)] \right|_o^{t_n}$$

$$+ \frac{\epsilon_m\, t_n}{\omega^m\ |F^*(\omega)|} \tag{A-50}$$

and

$$|\sin(\psi - \psi^*)| \leq \sum_{j=1}^{m-1} \frac{1}{\omega^{j+1}\ |F^*(\omega)|} \left| \frac{d^j}{dt^j} [f(t) - f^*(t)] \right|_o^{t_n}$$

$$+ \frac{\epsilon_m\, t_n}{\omega^m\ |F^*(\omega)|} \quad . \tag{A-51}$$

Proof:

$$F(\omega) - F^*(\omega) = \int_o^{t_n} [f(t) - f^*(t)]\, e^{-i\omega t}\, dt \quad . \tag{A-52}$$

Integrating by parts,

$$F(\omega) = F^*(\omega) = - \left\{[f(t) - f^*(t)]\right\} \frac{1}{(i\omega)} e^{-i\omega t} \Bigg|_o^{t_n}$$

$$- \left\{\frac{d}{dt}[f(t) - f^*(t)]\right\} \left\{\frac{1}{(i\omega)^2} e^{-i\omega t}\right\} \Bigg|_o^{t_n} - \ldots$$

$$- \left\{\frac{d^{m-1}}{dt^{m-1}}[f(t) - f^*(t)]\right\} \left\{\frac{1}{(i\omega)^m} e^{-i\omega t}\right\} \Bigg|_o^{t_n} \tag{A-53}$$

$$+ \int_{o}^{t_n} \frac{1}{(i\omega)^m} e^{-i\omega t} \frac{d^m}{dt^m} [f(t) - f^*(t)] \, dt \tag{A-53}$$

$$= - e^{-i\omega t} \sum_{j=1}^{m-1} \frac{d^j}{dt^j} [f(t) - f^*(t)] \frac{1}{(i\omega)^{j+1}} \Bigg|_{o}^{t_n}$$

$$+ \frac{1}{(i\omega)^m} \int_{o}^{t_n} e^{-i\omega t} \frac{d^m}{dt^m} [f(t) - f^*(t)] \, dt \tag{A-54}$$

then

$$|F(\omega) - F^*(\omega)| \leq \sum_{j=1}^{m-1} \frac{1}{\omega^{j+1}} \left| \frac{d^j}{dt^j} [f(t) - f^*(t)] \right|_{o}^{t_n}$$

$$+ \frac{1}{\omega^m} \int_{o}^{t_n} \left| \frac{d^m}{dt^m} [f(t) - f^*(t)] \right| dt \quad . \tag{A-55}$$

By hypothesis,

$$\frac{d^m}{dt^m} \left| [f(t) - f^*(t)] \right| \leq \epsilon_m$$

and since

$$\big| |F(\omega)| - |F^*(\omega)| \big| \leq |F(\omega) - F^*(\omega)|$$

$$\frac{\big| |F(\omega)| - |F^*(\omega)| \big|}{|F^*(\omega)|} \leq \sum_{j=1}^{m-1} \frac{1}{\omega^{j+1} \; |F^*(\omega)|} \left| \frac{d^j}{dt^j} [f(t) - f^*(t)] \right|_{o}^{t_n}$$

$$+ \frac{\epsilon_m \; t_n}{\omega^m \; |F^*(\omega)|} \quad . \tag{A-56}$$

Using Lemma I,

$$|\sin (\psi - \psi^*)| \leq \sum_{j=1}^{n} \frac{1}{\omega^{j+1} \; |F^*(\omega)|} \left| \frac{d^j}{dt^j} [f(t) - f^*(t)] \right|_{o}^{t_n}$$

$$+ \frac{\epsilon_m \; t_n}{\omega^m \; |F^*(\omega)|} \quad . \tag{A-57}$$

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APPENDIX B -- LISTING OF THE FORTRAN AND MAP SOURCE PROGRAMS USED IN SPORT

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```
$FILE      'FTC03.',U03,U03,BLOCK=0801,SINGLE,LRL=0800,RCT=0001
$ETC       EOR=REORX.,EOF=REOFX.,ERR=RERRX.,TYPE3
$FILE      'FTC04.',U04,U04,BLOCK=0601,SINGLE,LRL=0600,RCT=0001
$ETC       EOR=REORX.,EOF=REOFX.,ERR=RERRX.,TYPE3
$FILE      'FTC08.',U05,U05,BLOCK=0401,SINGLE,LRL=0400,RCT=0001
$ETC       EOR=REORX.,EOF=REOFX.,ERR=RERRX.,TYPE3
$FILE      'FTC09.',U06,U06,BLOCK=0401,SINGLE,LRL=0400,RCT=0001
$ETC       EOR=REORX.,EOF=REOFX.,ERR=RERRX.,TYPE3
```

```
C       FORTRAN ROUTINE WHICH READS THE PART AND CHANNEL CARDS, CALLS
C       THE INPUT SUBROUTINES AND CALLS THE PROCESSING SUBROUTINES
C       THROUGH SUBROUTINE SUBCNT.
C
        COMMON DATA(2021),LOM,IFINC,IPGNO,IHED(14),DATE(2)
        DIMENSION IDNO(50),TMIN(50),TMAX(50),NCFDAT(50),TMSHF(50),
      1 NCFTIM(50),DTSHF(50),IFILNO(50),TITLE(12)
        EQUIVALENCE (IHED(2),TITLE)
        INTEGER FRCODE,CHCODE,PART,AUTO
        LOGICAL SWTCH1
        REAL NCFT,NCFDAT,NCFD,NCFTIM
C
        IA=315
        CALL SET(IA)
        CALL TIMX(ITM)
        CALL TODAY(DATE)
        IHED( 1) = -17997958192
        IHED(14) = -17997958192
        IFINC=0
        ILRLNO=0
   50   IPGNO=1
C
C       READ 'PART' CARD
C
        READ(5,1)PART,FRCODE,ICODE,CHCODE,IPNLST,LCODE,AUTO,IRDP,TITLE
    1   FORMAT(3I1,I3,2I1,A1,I1,11A6,1A4)
        WRITE(6,2) DATE,PART,FRCODE,ICODE,CHCODE,IPNLST,LCODE,AUTO,IRDP,
      1 TITLE
    2   FORMAT(1H1,8H SPORT   A6,A2,27X,45H SYSTEM FOR PROCESSING REACTOR
      1TRANSIENT DATA34X,9H PAGE    1 // 16H   PART CARD WAS 3I1,I3,2I1,A1,
      2 I1,1X,11A6,1A4 )
        IF(IFINC.EQ.0 .AND. AUTO.EQ. -20145441840) IFINC=-0
        SWTCH1=CHCODE.LT.0
        NOCHNL=IABS(CHCODE)
        IF((PART.LT.4).OR.(ICODE.EQ.5)) GO TO 100
C
        CALL SUBCNT(PART,FRCODE,ICODE,IPNLST,K,DT)
        GO TO 150
C
C       READ CHANNEL CARDS
C
  100   DO 105 I=1,NOCHNL
        READ(5,4)  IDNO(I),TMIN(I),TMAX(I),NCFTIM(I),NCFDAT(I),TMSHF(I),
      1 DTSHF(I),IRLNO,IFILNO(I)
    4   FORMAT(I10,6E10.8,2I4)
        IF((TMAX(I)).EQ.-0.0) TMAX(I)=1.0E+30
        IF((NCFTIM(I)).EQ.-0.0) NCFTIM(I)=1.0
        IF((NCFDAT(I)).EQ.-0.0) NCFDAT(I)=1.0
        IF(I.EQ.1) GO TO 101
        IF(SWTCH1) TMIN(I)=TMAX(I-1)
        GO TO 105
C
C       CHECK REEL NUMBER (IF ANY)
C
  101   IF(ICODE.NE.5) GO TO 102
```

```
      IRLNMB=IRLNO
      IF(IRLNMB.EQ.0)  GO TO 103
      WRITE(6,104) IRLNMB
  104 FORMAT(1H0,12H REEL NUMBERI5)
      IF(IRLNMB.EQ.ILRLNO)  IRLNMB=2220000222
  103 ILRLNO=IRLNO
  102 WRITE(6,3)
    3 FORMAT(1H0,30H CHANNEL    FILE NO      MINIMUM,8X,8H MAXIMUM,8X,
     1 25H NORMALIZING COEFFICIENTS,6X,27H TIME SHIFT      DATA SHIFT /
     2 29H    ID NO     (IF ANY)      TIME,11X,5H TIME,12X,5H TIME,11X,
     3 5H DATA / )
C
  105 WRITE(6,5) IDNO(I),IFILNO(I),TMIN(I),TMAX(I),NCFTIM(I),NCFDAT(I),
     1 TMSHF(I),DTSHF(I)
    5 FORMAT(I11,I7,3X,3(F14.6,2X),1PE14.7,2X,0PF14.6,2X,1PE14.7)
C
C     MAIN LOOP
C
      IA=90
      IF(.NOT.SWTCH1) CALL SET(IA)
  110 DO 120 I=1,NOCHNL
      IE=0
      IX=0
      IF(.NOT.SWTCH1) IE=1
      IF(I.EQ.1) IE=2*CHCODE/NOCHNL
      IF(.NOT.SWTCH1 .OR. I.EQ.NOCHNL) IX=1
      CALL GNTAPE(PART,ICODE,IE,IX,IPNLST,LCODE,IDNO(I),K,
     1 TMIN(I),TMAX(I),NCFTIM(I),NCFDAT(I),TMSHF(I),DTSHF(I),
     2 IRLNMB,IRDP,IFILNO(I) )
  119 IF(IX.EQ.1) CALL SUBCNT(PART,FRCODE,ICODE,IPNLST,K,TMAX(I) )
  120 CONTINUE
C
C     END OF PROBLEM
C
  150 CALL ETIMX(ITM,IETM,RETS)
      WRITE(6,7)IETM,RETS
    7 FORMAT(1H0,27H TOTAL PROBLEM TIME WAS     I4,5H MIN F4.1,4H SEC )
  151 READ(5,6)NOM
    6 FORMAT(1A2)
      IF(NOM.EQ. -13216451632)  GO TO 50
      IF(NOM.NE. -13736545328)  GO TO 151
C
C     END OF PROBLEM SET
C
  160 IF(IFINC.EQ.0)  STOP
C
C     INDICATE END OF PLOT REEL
C
      CALL DRAW(0,0,0,0,0,0,0.,0.,0.,0.,12.,0.,0.,8.,0.,0.,0,0.)
      CALL SYMBLJ(0.0,0.0,0.14,19H END OF SPORT PLOTS,90.0,19)
      CALL PLOT(5.0,-1.0,-3)
C
C     DISMOUNT PLOT TAPE
C
      CALL TYPE(1H ,1,0)
```

```
      CALL TYPE(16H       THERE WERE,16,0)                                  MAIN1100
      CALL TYPEN(IFINC-1)                                                   MAIN1110
      CALL TYPE(19H    PLOTS GENERATED,19,0)                                MAIN1120
      CALL TYPE(1H ,1,0)                                                    MAIN1130
      CALL FINI                                                             MAIN1140
      STOP                                                                  MAIN1150
C                                                                           MAIN1160
      END                                                                   MAIN1170
```

```
C       FORTRAN SUBROUTINE WHICH READS THE SPORT INPUT DATA (EITHER
C       DIRECTLY OR BY CALLING SUBROUTINES SPERT1,DAT650 OR TREAD)
C       AND PERFORMS THE DATA PREPARATION INDICATED ON THE PART AND
C       CHANNEL CARDS.
C
        SUBROUTINE GNTAPE(PART,ICODE,IE,IX,IPNLST,LCCDE,ID,K,TMN,TMX,
     1 NCFT,NCFD,TSHFT,DSHFT,IRLNMB,IRDP,IFILNO )
C
        COMMON DATA(2021),LOM,IFINC,IPGNO,HEAD(14)
        DIMENSION X(8),A(7),B(7),FMT(14),C(600),D(800),ISTCR(800),SCT(2),
     1 SCD(2)
        INTEGER PART
        REAL NCFT,NCFD
        LOGICAL SWTCH1,SWTCH2,SWTCH3,SWTCH4,SWTCH5,SWTCH6,SWTCH7,SWTCH8
        EQUIVALENCE (DATA(19),ND,X),(DATA(20),TO,A),(DATA(21),DT),
     1 (DATA(27),D,ISTOR),(KR,K2),(JFILNO,SWTCH6),(DATA(17),IRECNO)
C
        SWTCH8=IABS(IE).EQ.2
        IF(IE.EQ.0)  GO TO 6400
        CALL TIMX(ITL)
        REWIND 4
        SCD(1)=+1.0E+30
        SCD(2)=-1.0E+30
        IF(.NOT.SWTCH8)  GO TO 6400
        IBLANK = -17997958192
        SWTCH7=ICODE.NE.5
        SWTCH4=LCODE.EQ.0
        SWTCH5=IRDP.NE.0
 6400   IF(.NOT.SWTCH7)  GO TO 500
C
C       CARD SECTION
C
        IF(IE.EQ.0) GO TO 449
        SWTCH1=.FALSE.
        K3=0
        KR=-1
        IEOF=0
        IF(IF.EQ.1) GO TO 440
        IF(ICODE.EQ.4)  READ(5,3) NOCHNL,FMT
    3   FORMAT(I1,13A6,1A1)
        KS=-7
        REWIND 3
C
C       PREPARE BINARY DATA TAPE- ALL CHANNELS
C
   30   GO TO(100,200,300,400),ICODE
  100   CALL SPRT13(X)
        IF(LOM.EQ.1) GO TO 100
        GO TO 470
  200   READ(5,1)ND,(A(J),B(J),J=1,7)
    1   FORMAT(I10,7(F8.8,A2))
        GO TO 310
  300   READ(5,2)ND,NDL,(A(J),B(J),J=1,7)
    2   FORMAT(I9,A1,7(F8.8,A2))
        CALL ID650(ND,NDL)
```

```
  310 CALL DAT650(A,B,7)
      GO TO 470
  400 READ(5,FMT)ND,A(1),(A(J+1),J=1,NOCHNL)
  470 KS=KS+8
      ISTOR(KS)=ND
      D(KS+1)=X(2)
      D(KS+2)=X(3)
      D(KS+3)=X(4)
      D(KS+4)=X(5)
      D(KS+5)=X(6)
      D(KS+6)=X(7)
      D(KS+7)=X(8)
      IF((KS.LT.793).AND.(ND.NE.0))  GO TO 30
      KS=-7
      WRITE(3) D
      IF(ND.NE.0)  GO TO 30
C
C     PREPARE NORMALIZED DATA TAPE- CHANNEL 'ID'
C
  440 REWIND 3
  448 KS=-7
      READ(3) D
  450 KS=KS+8
      IF(KS.EQ.801)  GO TO 448
      LD=ISTOR(KS)
      IF(LD.EQ.0)  GO TO 522
      IF(SWTCH1)  GO TO 449
C
C     ASSEMBLE PARAMETERS FOR FIRST RECORD
C
  601 SWTCH1=.TRUE.
      NID=ID
      IF(IE.NE.-2)  GO TO 4602
      NID=0
 4602 DELT=(D(794)-D(2))/99.0
      WRITE(4) LD,NID,DELT
      GO TO 4010
C
  449 T=D(KS+1)*NCFT+TSHFT
  451 IF(T.LT.TMN)  GO TO 450
      IF(T.GE.TMX)  GO TO 522
  460 IKS=KS+1+ID
      VALUE=D(IKS)*NCFD+DSHFT
  602 GO TO 566
C
C     DIGITAL TAPE SECTION
C
  500 IF(.NOT.SWTCH8)  GO TO 502
      IF(IRLNMB.EQ.222C0000222)  GO TO 4005
C
C     MOUNT DATA TAPE
C
  501 CALL TYPE(1H ,1,0)
      IF(IRLNMB.NE.0)  GO TO 4501
      CALL TYPE(22H MOUNT REEL CONTAINING,22,0)
```

```
      CALL TYPE(16H      DATA RECORD,16,0)                             GNTP1100
      KD=ID                                                            GNTP1110
      GO TO 4502                                                       GNTP1120
4501  CALL TYPE(15H      MOUNT REEL,15,0)                              GNTP1130
      KD=IRLNMB                                                        GNTP1140
4502  CALL TYPEN(KD)                                                   GNTP1150
      CALL TYPE(14H      ON T,C,6,14,0)                                GNTP1160
      CALL TYPE(1H ,1,0)                                               GNTP1170
      CALL TIMX(ITM)                                                   GNTP1180
      CALL TYPE(24H PRESS START TO CONTINUE,24,1)                      GNTP1190
      CALL ETIMX(ITM,IETM,RETS)                                        GNTP1200
      WRITE(6,4000) IETM,RETS                                          GNTP1210
4000  FORMAT(1H0,27H DATA TAPE MOUNTING TIME - I4,5H MIN F4.1,4H SEC ) GNTP1220
C                                                                      GNTP1230
4005  REWIND 10                                                        GNTP1240
      NTCT=1                                                           GNTP1250
      GO TO 1502                                                       GNTP1260
C                                                                      GNTP1270
 502  CALL BACK(NTCT,0)                                                GNTP1280
      NTCT=0                                                           GNTP1290
1502  IF(IE.EQ.0)  GO TO 503                                           GNTP1300
C                                                                      GNTP1310
C     ASSEMBLE PARAMETERS FOR FIRST RECORD                             GNTP1320
C                                                                      GNTP1330
      LD=ID                                                            GNTP1340
      NID=(LD/1000)*1000                                               GNTP1350
      IF(IE.EQ.-2) LD=NID                                              GNTP1360
      NID=LD-NID                                                       GNTP1370
4010  CALL HEADER                                                      GNTP1380
      IF(IPNLST.EQ.0) GO TO 2503                                       GNTP1390
      IF(IE.EQ.-2)  GO TO 2502                                         GNTP1400
      IF(NID.EQ.0)  NID=1                                              GNTP1410
      WRITE(6,4) LD,NID                                                GNTP1420
   4  FORMAT(1H0,41X,26HNORMALIZED DATA  RECORD NOI11,9H  CHANNELI4 / )GNTP1430
      GO TO 3502                                                       GNTP1440
2502  WRITE(6,12) LD                                                   GNTP1450
  12  FORMAT(1H0,48X,27HNORMALIZED COMPOSITE DATA  I10 / )             GNTP1460
3502  IF(IPNLST.EQ.2)  PUNCH 8,LD                                      GNTP1470
   8  FORMAT(5X,27HNORMALIZED DATA  RECORD NO I10,10H  CHANNEL I3 )    GNTP1480
      IF(.NOT.SWTCH4)  WRITE(6,7)                                      GNTP1490
   7  FORMAT(1H ,49X,35H LN(DATA) TAKEN IN INPUT SUBROUTINE  /  )      GNTP1500
2503  IF(SWTCH7)  GO TO 449                                            GNTP1510
      K3=0                                                             GNTP1520
      K2=-1                                                            GNTP1530
C                                                                      GNTP1540
C                                                                      GNTP1550
C     FIND RECORD WITH ID=ND                                           GNTP1560
C                                                                      GNTP1570
 503  JFILNO=IFILNO                                                    GNTP1580
3503  CALL TREAD(IEOF)                                                 GNTP1590
      IF(IEOF.NE.0)  GO TO 522                                         GNTP1600
      IF(.NOT.SWTCH8)  NTCT=NTCT+1                                     GNTP1610
      IF(.NOT.SWTCH6 .AND. IRECNO.NE.IFILNO)  GO TO 3503               GNTP1620
      IF(ID.EQ.ND)  GO TO 3504                                         GNTP1630
      IF(SWTCH6)  GO TO 3503                                           GNTP1640
```

```
      WRITE(6,3505)  IFILNO,ND,ID
 3505 FORMAT(1H0,16H ID NO OF RECORDI4  ,5H WAS I10,6H, NOT I1C )
      GO TO 522
C
 3504 DELT=DT*NCFT
      IF(IE.NE.0)  WRITE(4) LD,NID,DELT
C
  504 TO2=TO*NCFT+TSHFT
C
C     PROCESS CURRENT RECORD
C
      DO 526 J=22,2021
      T=FLOAT(J-22)*DELT+TO2
      IF(T.LT.TMN) GO TO 526
      IF(T.LT.TMX) GO TO 530
C
C     PROCESS FINAL RECORD
C
  522 IF(IX.EQ.0) RETURN
      TMX=DELT
      K=K3*300+(K2+1)/2
      KK2=K2+2
      C(KK2)=1.0E+30
      C(KK2+1)=0.0
      IF(K.EQ.0)  GO TO 576
      IF(SWTCH5 .AND. K3.EQ.0)  SCT(1)=C(1)
      IF(IPNLST.EQ.0)  GO TO 535
C
C     PRINT FINAL PAGE
C
  705 IF(K2.EQ.-1)  GO TO 550
      KT=K2/100+1
      GO TO(536,537,538,539,540,541),KT
  536 WRITE(6,17)C(1),C(2),(C(I+2),C(I+3),I=1,K2,2)
   17 FORMAT(1X,0PF10.6,1X,1PE10.3)
      GO TO 535
  537 WRITE(6,18)(C(I-98),C(I-97),C(I+2),C(I+3),I=99,K2,2)
   18 FORMAT(2(1X,0PF10.6,1X,1PE10.3))
      WRITE(6,17)(C(I-96),C(I-95),I=K2,195,2)
      GO TO 535
  538 WRITE(6,19)(C(I-198),C(I-197),C(I-98),C(I-97),C(I+2),C(I+3),
     1 I=199,K2,2)
   19 FORMAT(3(1X,0PF10.6,1X,1PE10.3))
      WRITE(6,18)(C(I-196),C(I-195),C(I-96),C(I-95),I=K2,295,2)
      GO TO 535
  539 WRITE(6,20)(C(I-298),C(I-297),C(I-198),C(I-197),C(I-98),C(I-97),
     1 C(I+2),C(I+3),I=299,K2,2)
   20 FORMAT(4(1X,0PF10.6,1X,1PE10.3))
      WRITE(6,19)(C(I-296),C(I-295),C(I-196),C(I-195),C(I-96),C(I-95),
     1 I=K2,395,2)
      GO TO 535
  540 WRITE(6,21)(C(I-398),C(I-397),C(I-298),C(I-297),C(I-198),
     1 C(I-197),C(I-98),C(I-97),C(I+2),C(I+3),I=399,K2,2)
   21 FORMAT(5(1X,0PF10.6,1X,1PE10.3))
      WRITE(6,20)(C(I-396),C(I-395),C(I-296),C(I-295),C(I-196),
```

```
     1 C(I-195),C(I-96),C(I-95),I=K2,495,2)
       GO TO 535
  541  WRITE(6,10)(C(I-498),C(I-497),C(I-398),C(I-397),C(I-298),
     1 C(I-297),C(I-198),C(I-197),C(I-98),C(I-97),C(I+2),C(I+3),
     2 I=499,K2,2)
   10  FORMAT(6(1X,0PF10.6,1X,1PE10.3))
       WRITE(6,21)(C(I-496),C(I-495),C(I-396),C(I-395),C(I-296),
     1 C(I-295),C(I-196),C(I-195),C(I-96),C(I-95),I=K2,595,2)
       GO TO 535
  550  WRITE(6,17)C(1),C(2)
       GO TO 535
  576  IF(IEOF.EQ.0) WRITE(6,22)
   22  FORMAT(1H0,27H NO DATA IN RANGE SPECIFIED )
       IF(IEOF.NE.0) WRITE(4) LD,NID,DELT
  535  IF(IEOF.NE.0)  WRITE(6,13)
   13  FORMAT(1H0,42H END-OF-FILE MARK ENCOUNTERED CN DATA TAPE )
       WRITE(4) C
       IF(IPNLST.NE.2)  GO TO 3001
       PUNCH 6,(LD,C(I),C(I+1),C(I+1),I=1,K2,2)
    6  FORMAT(I10,5X,0PF12.6,5X,1PE14.7,5X,0PF20.8)
 3001  CALL ETIMX(ITL,IPREPM,RPREPS)
       IF(SWTCH5) GO TO 3005
       WRITE(6,3003) IPREPM,RPREPS
 3003  FORMAT(1H0,27H DATA PREPARATION REQUIRED I4,5H MIN F4.1,4H SECA1,
     1 22HAND DATA PLOT REQUIREDI3,5H MIN F4.1,4H SEC )
       RETURN
C
C      COMPUTE DATA VALUE AND STORE IN ARRAY 'C'
C
  530  VALUE=DATA(J)*NCFD+DSHFT
  566  IF(SWTCH4)  GO TO 531
       IF(VALUE.LE.0.0)  GO TO 525
       VALUE=ALOG(VALUE)
  531  K2=K2+2
       C(K2)=T
       C(K2+1)=VALUE
       IF(K2.LT.599)  GO TO 525
       WRITE(4) C
       K3=K3+1
       K2=-1
       IF(SWTCH5.AND.K3.EQ.1)  SCT(1)=C(1)
       IF(SWTCH5)  CALL MAXMIN(SCD,C,2,600,2)
       IF(IPNLST.EQ.0)  GO TO 525
       WRITE(6,10)(C(I),C(I+1),C(I+100),C(I+101),C(I+200),C(I+201),
     1 C(I+300),C(I+301),C(I+400),C(I+401),C(I+500),C(I+501),I=1,99,2)
       CALL HEADER
       WRITE(6,4) LD,NID
       IF(IPNLST.NE.2)  GO TO 525
       PUNCH 6,(LD,C(I),C(I+1),C(I+1),I=1,599,2)
  525  IF(SWTCH7)  GO TO 450
  526  CONTINUE
C
C      CHECK NEXT RECORD
C
       CALL TREAD(IEOF)
```

```
      IF(IEOF.NE.0)  GO TO 522
      NTCT=NTCT+1
      IF(ND.NE.ID)  GO TO 522
      DELT=DT*NCFT
      IF( INT( (T+DELT-TSHFT-TO*NCFT)*1.0E+6 ) .NE.0 )  GO TO 522
      GO TO 504
C
C     DATA PLOT SECTION
C
 3005 IF(K.EQ.0) GO TO 1923
      SCT(2)=C(599)
      IF(K2.NE.-1)  SCT(2)=C(K2)
      REWIND 4
C
C     DRAW PLOT
C
      IPPR=IRDP
      IF(.NOT.SWTCH4)  IPPR=IPPR+2
      CALL DRAW(0,1,IPPR,K,300,2,.TRUE.,C,SCT,SCD,
     1 10.0,TMIN,DTM,7.C,DMIN,DDAT,
     2 HEAD,20H     CATA VALUE       )
C
 1923 CALL ETIMX(ITL,IPLTM,RPLTS)
      WRITE(6,3003) IPREPM,RPREPS,IBLANK,IPLTM,RPLTS
      RETURN
C
      END
```

```
C       FORTRAN SUBROUTINE WHICH CONTROLS THE ORDER IN WHICH THE PRO-
C       CESSING PROGRAMS(SMOOTH,REACTIVITY AND FREQUENCY RESPONSE) ARE
C       CALLED.
C
        SUBROUTINE SUBCNT(PART,FRCODE,ICODE,IPNLST,K,DT )
C
        COMMON DATA(2021),LOM,IFINC,IPGNO,IHEAD(14),DATE(2)
        INTEGER PART,FRCODE
C
        IF(PART.EQ.0)  RETURN
        GO TO(100,100,100,400,500),PART
C
  100   CALL SMOOTH(PART,ICODE,K,DT)
        IF(LOM.EQ.1) K=0
  120   GO TO(600,150,190),PART
  150   CALL REACT(K,DT,FRCODE)
  190   IF(FRCODE.EQ.0) GO TO 600
        CALL FREQ(PART,ICODE,K,DT)
  600   RETURN
C
  500   IF(ICODE.EQ.5)  GO TO 190
  400   CALL INPUT(PART,ICODE,K,DT,IPNLST)
        IF(K.EQ.0)  RETURN
        IF(PART.EQ.4)  GO TO 150
        GO TO 190
C
        END
```

```
**                                                                    TREDO000
**      MAP SUBROUTINE USED TO READ TYPE-5 SPORT DATA. G A CAZIER     TREDO010
**                                                                    TREDO020
        ENTRY   TREAD                                                 TREDO030
**                                                                    TREDO040
TREAD   PZE     **                                                    TREDO050
        SXA     X4,4                                                  TREDO060
        TSX     S.IOOP,4                                              TREDO070
        IORBS   TBUFF                                                 TREDO080
        PZE     S.SU07                                                TREDO090
        CAL     S.SSCH                                                TREDO100
        TZE     ENDFIL                                                TREDO110
        LAC     TREAD,4                                               TREDO120
        CLA     =00                                                   TREDO130
        STO*    2,4                                                   TREDO140
X4      AXT     **,4                                                  TREDO150
        TRA*    TREAD                                                 TREDO160
ENDFIL  LAC     TREAD,4                                               TREDO170
        CLA     =07                                                   TREDO180
        STO*    2,4                                                   TREDO190
        TRA     X4                                                    TREDO200
TBUFF   PZE     DATA,,2021                                            TREDO210
        CONTRL  //                                                    TREDO220
        USE     //                                                    TREDO230
DATA    BSS     2021                                                  TREDO240

        USE     PREVIOUS                                              TREDO250
            LITERALS

        EXTERN      S.SSCH   GENERATED
        EXTERN      S.SU07   GENERATED
        EXTERN      S.IOOP   GENERATED
        END                                                           TREDO260
```

```
**                                                                      BACK0000
**      MAP SUBROUTINE USED TO POSITION INPUT DATA TAPE.  G A CAZIER    BACK0010
**                                                                      BACK0020
        ENTRY   BACK                                                    BACK0030
**                                                                      BACK0040
BACK    PZE     **                                                      BACK0050
        SXA     SAV4,4                                                  BACK0060
        LAC     BACK,4                                                  BACK0070
        CLA*    2,4                                                     BACK0080
        STA     SPAC                                                    BACK0090
        CLA*    3,4                                                     BACK0100
        ALS     18                                                      BACK0110
        STD     SPAC                                                    BACK0120
        TSX     S.IOOP,4                                                BACK0130
        IOSKP   SPAC                                                    BACK0140
        PZE     S.SU07                                                  BACK0150
SAV4    AXT     **,4                                                    BACK0160
        TRA*    BACK                                                    BACK0170
SPAC    MZE     **,,**                                                  BACK0180
        EXTERN      S.SU07   GENERATED
        EXTERN      S.IOOP   GENERATED
        END                                                             BACK0190
```

```
**                                                                      TYPE0000
**      MAP SUBROUTINE USED TO PRINT CONSOLE MESSAGES.   K R DICKEY     TYPE0010
**                                                                      TYPE0020
        ENTRY   TYPE                                                    TYPE0030
**                                                                      TYPE0040
TYPE    PZE     **                                                      TYPE0050
        SXA     NOPAUS,4                                                TYPE0060
        LAC     TYPE,4                                                  TYPE0070
        CLA     2,4                HOLL ADRESS IN AC                    TYPE0080
        STA     SEQUEN                                                  TYPE0090
        CLA*    3,4                COUNT                                TYPE0100
        ALS     18                                                      TYPE0110
        STD     SEQUEN                                                  TYPE0120
        TSX     S.XPRT,4                                                TYPE0130
SEQUEN  PZE     **,,**                                                  TYPE0140
        LAC     TYPE,4                                                  TYPE0150
        CLA*    4,4                                                     TYPE0160
        TZE     NOPAUS                                                  TYPE0170
        TSX     S.XPSE,4                                                TYPE0180
NOPAUS  AXT     **,4                                                    TYPE0190
        TRA*    TYPE                                                    TYPE0200
        EXTERN      S.XPRT    GENERATED
        EXTERN      S.XPSE    GENERATED
        END                                                             TYPE0210
```

```
C         FORTRAN SUBROUTINE USED TO PRINT INTEGER NUMBERS AS CONSOLE
C         MESSAGES.
C
          SUBROUTINE TYPEN(ID)
C
          DIMENSION QUAN(2)
C
          CALL BBCD1(ID,QUAN(1),QUAN(2) )
          CALL TYPE(QUAN,12,0)
          RETURN
C
          END
```

```
**
**      MAP SUBROUTINE USED TO CONVERT INTEGER NUMBERS TO BCD.
**      SCOTT BENNION
**
        ENTRY   BBCD1
        ENTRY   BBCD1.
**
BBCD1.  MSM     BBCD1-2                 TSX ENTRY...............TSX   BBCD1.,4
        SXA     SAVE2,2                                         PZE   BIN
        LDQ     ZERO                      (... CYCLES)          PZE   BCD1
        CLA*    1,4                                             PZE   BCD2
        SSP
        LRS     4
        VDP     PTEN,,4
        STQ     UPBCD           P=10
        LRS     4
        VDP     PTEN+1,,4
        STQ     UPBCD+1         P=9
        LRS     4
        VDP     PTEN+2,,4
        STQ     UPBCD+2         P=8
        LRS     4
        VDP     PTEN+3,,4
        STQ     UPBCD+3         P=7
        LRS     4
        VDP     PTEN+4,,4

        STQ     UPBCD+4         P=6
        LRS     4
        VDP     PTEN+5,,4
        STQ     UPBCD+5         P=5
        LRS     4
        VDP     PTEN+6,,4
        STQ     UPBCD+6         P=4
        LRS     4
        VDP     PTEN+7,,4
        STQ     UPBCD+7         P=3
        LRS     4
        VDP     PTEN+8,,4
        STQ     UPBCD+8         P=2
        LRS     4
        VDP     PTEN+9,,4
        STQ     UPBCD+9         P=1
        STO     UPBCD+10        P=0
        AXT     11,2            COUNT AND SUPPRESS LEADING ZEROS
SPZ     CLA     UPBCD+11,2

        TNZ     TFS
        CAL     BLANK           IR2=THE LOCATION OF THE DIGIT NOT ZERO
        STO     UPBCD+11,2
        TIX     SPZ,2,1
        STZ     UPBCD+10
```

```
 TFS    CAL*    1,4
        ANA     STEST
        TZE     PACK
        CAL     MINUS
        STO     UPBCD+10,2
PACK    CAL     UPBCD+4
        LGR     6
        CAL     UPBCD+3
        LGR     6
        CAL     UPBCD+2
        LGR     6
        CAL     UPBCD+1
        LGR     6
        CAL     UPBCD

        LGR     6
        CAL     BLANK
        LGR     6
 WRD2   STQ*    2,4
        CAL     UPBCD+10
        LGR     6
        CAL     UPBCD+9
        LGR     6
        CAL     UPBCD+8
        LGR     6
        CAL     UPBCD+7           PACK SECOND BCD  WORD
        LGR     6
        CAL     UPBCD+6
        LGR     6
        CAL     UPBCD+5
        LGR     6
 WRD1   STQ*    3,4
 SAVE2  AXT     0,2
        BRA     BBCD1+5

        AXT     **,4
BBCD1   TRA     **                  CALL ENTRY..CALL BBCD1(BIN,BCD1,BCD2)
        MSP     BBCD1-2
        SXA     BBCD1-1,4                         (... CYCLES)
        LAC     BBCD1,4
        TXI     BBCD1.+1,4,-1
        TRA     4,4
 PTEN   DEC     10000000000       10 TO 10TH
        DEC     1000000000        10 TO  9TH
        DEC     100000000         10 TO  8TH
        DEC     10000000          10 TO  7TH
        DEC     1000000           10 TO  6TH
        DEC     100000            10 TO  5TH
        DEC     10000             10 TO  4TH
        DEC     1000              10 TO  3RD
        DEC     100               10 TO  2ND
        DEC     10                10 TO  1ST
 BLANK  OCT     °606060606060
```

```
STEST  OCT     400000000000                                          BBCD1010

MINUS  OCT     000000000040                                          BBCD1020
ZERO   PZE                                                           BBCD1030
 UPBCD BSS     11                                                    BBCD1040
       END                                                           BBCD1050
```

```
C     FORTRAN SUBROUTINE TO PRINT PAGE HEADINGS.                         HEAD0000
C                                                                        HEAD0010
      SUBROUTINE HEADER                                                  HEAD0020
C                                                                        HEAD0030
      COMMON DATA(2021),LOM,IEINC,IPGNO,IHEAD(14),DATE(2)                HEAD0040
C                                                                        HEAD0050
      IPGNO=IPGNO+1                                                      HEAD0060
      WRITE(6,1) DATE,IHEAD,IPGNO                                        HEAD0070
    1 FORMAT(1H1,8H SPORT  A6,A2,9X,12A6,2A4,17X,5H PAGEI4 )             HEAD0080
      RETURN                                                             HEAD0090
C                                                                        HEAD0100
      END                                                                HEAD0120
```

```
**                                                                    TDAY0000
**       MAP SUBROUTINE USED TO REFERENCE CURRENT DATE.   N H MARSHALL TDAY0010
**                                                                    TDAY0020
         ENTRY    TODAY                                               TDAY0030
**                                                                    TDAY0040
TODAY    TRA      **                                                  TDAY0050
         SXA      X4,4                                                TDAY0060
         LAC      TODAY,4                                             TDAY0070
         CLA      2,4                                                 TDAY0080
         PAC      ,4                                                  TDAY0090
         ZAC                                                          TDAY0100
         LGR      36                                                  TDAY0110
         CAL      S.SDAT                                              TDAY0120
         LGR      24                                                  TDAY0130
         ALS      6                                                   TDAY0140
         ADD      =H00000/                                            TDAY0150
         LGL      12                                                  TDAY0160
         ALS      6                                                   TDAY0170
         ADD      =H00000/                                            TDAY0180
         SLW      0,4                STORE MM/DD/  IN FIRST WORD      TDAY0190
         ZAC                                                          TDAY0200
         LGL      36                                                  TDAY0210
         ADD      =H00                                                TDAY0220
         SLW      1,4                STORE YY IN SECOND WORD          TDAY0230

X4       AXT      **,4                                                TDAY0240
         TRA*     TODAY                                               TDAY0250
            LITERALS

         EXTERN      S.SDAT   GENERATED
         END                                                          TDAY0260
```

```
C       FORTRAN SUBROUTINE WHICH COMPUTES THE PHASE ANGLE OF A COMPLEX
C       QUANTITY.  L E REESE
C
        SUBROUTINE ANGRAD(X,Y,TMAG,PHASE)
C
        COMMON DATA(2021),LOM
C
        TMAG=SQRT(X*X+Y*Y)
        IF (X) 3,2,4
    2   IF (Y) 5,7,6
    5   PHASE=4.7123890
        RETURN
    6   PHASE=1.5707963
        RETURN
    3   PHASE=ATAN(Y/X)+3.1415927
        RETURN
    4   IF (Y) 8,9,9
    8   PHASE=ATAN(Y/X)+6.2831853
        RETURN
    9   PHASE=ATAN(Y/X)
        RETURN
    7   PHASE=0.0
        RETURN
C
        END
```

```
**                                                                        SPRT0000
**       MAP SUBROUTINE USED TO READ TYPE-1 SPORT DATA.   R J WAGNER      SPRT0010
**                                                                        SPRT0020
         ENTRY    SPRT13                                                  SPRT0030
**                                                                        SPRT0040
         EXTERN   TSHIO.,RTNIO.,FMTSC.,FIL05.,HNLIO.,STHIO.,FIL06.,FILIO. SPRT0050
SPRT13   PZE      **                                                      SPRT0060
         SXA      X4,4                                                    SPRT0070
         SXA      X4+1,2                                                  SPRT0080
         SXA      X4+2,1                                                  SPRT0090
         LAC      SPRT13,4                                                SPRT0100
         CLA      2,4                                                     SPRT0110
         STA      XSIU                                                    SPRT0120
         STZ      LOM                                                     SPRT0130

AGAIN    TSX      TSHIO.,4                                                SPRT0140
         PZE      FIL05.                                                  SPRT0150
         MZE      FMT,,FMTSC.                                             SPRT0160
         AXT      14,4                                                    SPRT0170
         TSL      HNLIO.                                                  SPRT0180
         STO      CARD+14,4                                               SPRT0190
         TIX      *-2,4,1                                                 SPRT0200
         TSX      RTNIO.,4                                                SPRT0210
         AXT      0,4                                                     SPRT0220
         TSL      BCDBG             GET ID                                SPRT0230


         TXI      *+3,0,0                                                 SPRT0240
         PZE      CARD,,0                                                 SPRT0250
         PZE      10                                                      SPRT0260
         CLA      VALUE                                                   SPRT0270
XSIU     STO      **,4                                                    SPRT0280
         TSL      BCDBG             GET TIME                              SPRT0290
         TXI      *+3,0,0                                                 SPRT0300
         PZE      CARD+2,,0                                               SPRT0310
         PZE      6                                                       SPRT0320
         PCS      CARD+3,,0                                               SPRT0330
         TSX      MINUS,2                                                 SPRT0340
         TSL      BCDBG             GET CH 1                              SPRT0350
         TXI      *+3,0,0                                                 SPRT0360
         PZE      CARD+4,,1                                               SPRT0370
         PZE      3                                                       SPRT0380
         PCS      CARD+4,,4                                               SPRT0390
         TSX      MINUS,2                                                 SPRT0400
         TSL      BCDBG             GET CH2                               SPRT0410
         TXI      *+3,0,0                                                 SPRT0420


         PZE      CARD+5,,5                                               SPRT0430
         PZE      3                                                       SPRT0440
         PCS      CARD+6,,2                                               SPRT0450
         TSX      MINUS,2                                                 SPRT0460
         TSL      BCDBG             GET CH3                               SPRT0470
         TXI      *+3,0,0                                                 SPRT0480
```

```
        PZE     CARD+7,,3                                                SPRT0490
        PZE     3                                                        SPRT0500
        PCS     CARD+8,,0                                                SPRT0510
        TSX     MINUS,2                                                  SPRT0520
        TSL     BCDBG              GET CH4                               SPRT0530
        TXI     *+3,0,0                                                  SPRT0540
        PZE     CARD+9,,1                                                SPRT0550
        PZE     3                                                        SPRT0560
        PCS     CARD+9,,4                                                SPRT0570
        TSX     MINUS,2                                                  SPRT0580
        TSL     BCDBG              GET CH5                               SPRT0590
        TXI     *+3,0,0                                                  SPRT0600
        PZE     CARD+10,,5                                               SPRT0610

        PZE     3                                                        SPRT0620
        PCS     CARD+11,,2                                               SPRT0630
        TSX     MINUS,2                                                  SPRT0640
        TSL     BCDBG              GET CH6                               SPRT0650
        TXI     *+3,0,0                                                  SPRT0660
        PZE     CARD+12,,3                                               SPRT0670
        PZE     3                                                        SPRT0680
        PCS     CARD+13,,0                                               SPRT0690
        TSX     MINUS,2                                                  SPRT0700
X4      AXT     **,4                                                     SPRT0710
        AXT     **,2                                                     SPRT0720
        AXT     **,1                                                     SPRT0730
        TRA*    SPRT13                                                   SPRT0740
* BCD TO BINARY ROUTINE                                                  SPRT0750
BCDBG   PZE     **                                                       SPRT0760
        SXA     BCAX,4                                                   SPRT0770
        LAC     BCDBG,4                                                  SPRT0780
        CLA     1,4                                                      SPRT0790
        STA     PICK                                                     SPRT0800
        ARS     18                                                       SPRT0810

        SAC     PICK,,2                                                  SPRT0820
        SUB     =6                                                       SPRT0830
        PAX     ,2                                                       SPRT0840
        CLA     2,4                                                      SPRT0850
        PAX     ,4                                                       SPRT0860
        AXT     0,1                                                      SPRT0870
        STZ     VALUE                                                    SPRT0880
        STZ     COUNT                                                    SPRT0890
        ZAC                                                              SPRT0900
PICK    PCS     **,1,**                                                  SPRT0910
        CCS     JUNK,,5                                                  SPRT0920
        TRA     ERRM                                                     SPRT0930
        TRA     ERR                                                      SPRT0940
        LDQ     JUNK                                                     SPRT0950
        VMA     VALUE,,4                                                 SPRT0960
        LLS     4                                                        SPRT0970
        STO     VALUE                                                    SPRT0980
        TNX     BCAX-1,4,1                                               SPRT0990
```

```
        ZAC                                                      SPRT1000
        TNX     *+5,2,1                                          SPRT1010
        PCS     PICK,,2                                          SPRT1020
        ADD     =1                                               SPRT1030
        SAC     PICK,,2                                          SPRT1040
        TRA     PICK                                             SPRT1050
        AXT     6,2                                              SPRT1060
        TXI     *-3,1,-1                                         SPRT1070
BRA     BRN     ERMA                                             SPRT1080
BCAX    AXT     **,4                                             SPRT1090
        TRA*    BCDBG                                            SPRT1100
* MINUS ROUTINE                                                  SPRT1110
MINUS   CCS     JUNK,,2                                          SPRT1120
        TRA     *+2                                              SPRT1130
        TRA     *+5                                              SPRT1140
        CCS     JUNK,,1                                          SPRT1150
        TRA     ERR                                              SPRT1160
        TRA     *+3                                              SPRT1170
        TRA     ERR                                              SPRT1180
        MSM     VALUE                                            SPRT1190
        CLA     VALUE                                            SPRT1200
        ORA     =0233000000000                                   SPRT1210
        FAD     =0233000000000                                   SPRT1220
        TXI     *+1,4,-1                                         SPRT1230
        STO*    XSTO                                             SPRT1240
        TRA     1,2                                              SPRT1250
* ERROR ROUTINE                                                  SPRT1260
ERR     TSX     STHIO.,4                                         SPRT1270
        PZE     FIL06.                                           SPRT1280
        MZE     FMT1,,FMTSC.                                     SPRT1290
        AXT     14,4                                             SPRT1300
        CLA     CARD+14,4                                        SPRT1310
        TSL     HNLIO.                                           SPRT1320
        TIX     *-2,4,1                                          SPRT1330
        TSX     FILIO.,4                                         SPRT1340
        CLA     =1                                               SPRT1350
        STO     LOM                                              SPRT1360
        TRA     X4                                               SPRT1370
ERRM    CCS     JUNK,,1                                          SPRT1380
        TRA     ERR                                              SPRT1390
        TRA     *+2                                              SPRT1400
        TRA     ERR                                              SPRT1410
        CLA     COUNT                                            SPRT1420
        ADD     =1                                               SPRT1430
        STO     COUNT                                            SPRT1440
        MSM     BRA                                              SPRT1450
        TRA     PICK+8                                           SPRT1460
ERMA    MSP     BRA                                              SPRT1470
```

```
         LAC       BCDBG,4                                              SPRT1480
         CLA       2,4                                                  SPRT1490
         SUB       COUNT                                                SPRT1500
         TNZ       ERR                                                  SPRT1510
         MSM       VALUE                                                SPRT1520
         LXA       BCAX,4                                               SPRT1530
         TRA*      BCDBG                                                SPRT1540
ERMA1    TXL       ERMA2,4,-2                                           SPRT1550
         CLS       =6                                                   SPRT1560
         TRA       ERMA+2                                               SPRT1570
ERMA2    CLS       =3                                                   SPRT1580

         TRA       ERMA2                                                SPRT1590
FMT      BCI       1,(14A6)                                             SPRT1600
JUNK     OCT       006040000012                                         SPRT1610
FMT1     BCI       5,(15H CARD REJECTED-13A6,A2)                        SPRT1620


COUNT    BSS       1                                                    SPRT1630
VALUE    BSS       1                                                    SPRT1640
CARD     BSS       14                                                   SPRT1650
         CONTRL    //                                                   SPRT1660
         USE       //                                                   SPRT1670
DATA     BSS       2021                                                 SPRT1680
LOM      BSS       1                                                    SPRT1690
         USE       PREVIOUS                                             SPRT1700
            LITERALS


         END                                                            SPRT1710
1
```

```
**
**       MAP SUBROUTINE USED TO READ TYPE-2 AND TYPE-3 SPORT DATA.
**       L J GANNON AND R J WAGNER
**
         ENTRY     DAT650
**
         EXTERN    .EXP2.
*
DAT650   TRA       **          EXIT INSTRUCTION
         SXA       XA,4
         SXA       XA+1,1
         SXA       XA+2,2
         LAC       DAT650,4
         CLA       2,4
         ADD*      4,4
         STA       ADD1        ADDRESS OF A + N
         STA       ADD2        ADDRESS OF A + N
         CLA       3,4
         ADD*      4,4
         STA       BADD1       ADDRESS OF B + N
         STA       BADD2       ADDRESS OF B + N
         CLA*      4,4
         PAX       ,2          N IN INDEX REG 2
*
ADD1     CLA       **,2                    FRACTION
         TZE       CONT                    IF THE NO IS ZERO, NO CONVERSION
         STO       TEMP
BADD1    LDQ       **,2                    EXPONENT

BADD2    CAL       **,2                    EXPONENT
         ANA       =0004000000000          MASK TO KEEP MINUS SIGN
         ALS       6                       SHIFT SIGN INTO P BIT
         ORA       TEMP
         SLW       TEMP                    PUT SIGN ON FRACTION
         SLW*      ADD1
         ZAC
         LGL       6
         STO       TEMP1       HIGH ORDER DIGIT OF EXPONENT
         ZAC
         LGL       6
         ANA       =017        TAKE OFF SIGN BITS
         CAS       =012        SEE IF ZERO, + OR - ZERO HAS XX1010 CORE CODE
         TRA       *+2         NO
         ZAC                   YES, SET TO ZERO
         STO       TEMP2       LOW ORDER DIGIT OF EXPONENT
         LDQ       TEMP1
         MPY       =10         BCD TO BINARY
         LLS       35

         ADD       TEMP2
         SUB       =50         SUBTRACT BASE 50
         TZE       CONT        IF EXPONENT IS ZERO
```

```
        LRS     35      PLACE IN MQ                                      DT650500
        CLA     =10.                                                     DT650510
        TSL     .EXP2.  GO TO FLOAT NUMBER TO FIX POWER SUBROUTINE       DT650520
        LRS     35                                                       DT650530
        FMP     TEMP                                                     DT650540
ADD2    STO     **,2                                                     DT650550
CONT    TIX     ADD1,2,1                                                 DT650560
*                                                                        DT650570
XA      AXT     **,4                                                     DT650580
        AXT     **,1                                                     DT650590
        AXT     **,2                                                     DT650600
        TRA*    DAT650                                                   DT650610
*                                                                        DT650620
TEMP    BSS     1                                                        DT650630
TEMP1   BSS     1                                                        DT650640
TEMP2   BSS     1                                                        DT650650
           LITERALS

        END                                                              DT650660
0
```

```
**                                                              TIMX0000
**      MAP SUBROUTINE USED TO REFERENCE COMPUTER TIME CLOCK.  TIMX0010
**      L A SCHMITTROTH                                         TIMX0020
**                                                              TIMX0030
        ENTRY   TIMX                                            TIMX0040
**                                                              TIMX0050
TIMX    PZE     **                                              TIMX0060
        CLA     TIMX                                            TIMX0070
        ADD     =2                                              TIMX0080
        STA     STORE                                           TIMX0090
        CLA     5                                               TIMX0100
STORE   STO*    **                                              TIMX0110
        TRA*    TIMX                                            TIMX0120
           LITERALS
        END                                                     TIMX0130
```

```
C       FORTRAN SUBROUTINE WHICH CALCULATES ELAPSED COMPUTER TIME.
C
        SUBROUTINE ETIMX(ITX,IETM,RETS)
C
        CALL TIMX(JTX)
        IETM=(JTX-ITX)/3600
        RETS=FLOAT(JTX-ITX)/60.0-FLOAT(IETM*60)
        ITX=JTX
        RETURN
C
        END
```

```
C       FORTRAN SUBROUTINE WHICH SELECTS THE MINIMUM AND MAXIMUM VALUES
C       FROM AN ARRAY.
C
        SUBROUTINE MAXMIN(SCALE,ARRAY,ISTART,ITOTAL,IJUMP)
C
        DIMENSION SCALE(2),ARRAY(1)
C
        DO 25 I=ISTART,ITOTAL,IJUMP
        IF(ARRAY(I).LT.SCALE(1))  SCALE(1)=ARRAY(I)
        IF(ARRAY(I).LT.1.0E+30.AND.ARRAY(I).GT.SCALE(2))SCALE(2)=ARRAY(I)
   25   CONTINUE
        RETURN
C
        END
```

```
**                                                                    ID650000
**      MAP SUBROUTINE WHCIH STRIPS THE SIGN OFF AN INTEGER NUMBER.   ID650010
**      R L COATES                                                    ID650020
**                                                                    ID650030
        ENTRY    ID650                                                ID650040
**                                                                    ID650050
 ID650  PZE      **                                                   ID650060
        SXA      END,4                                                ID650070
        LAC      ID650,4                                              ID650080
        CAL*     3,4                                                  ID650090
        ANA      =0170000000000                                       ID650100
        LAS      =0120000000000                                       ID650110
        TRA      *+2                                                  ID650120
        ZAC                                                           ID650130
        LRS      30                                                   ID650140
        SLW*     3,4                                                  ID650150
        LDQ*     2,4                                                  ID650160
        MPY      =0000000000012                                       ID650170
        STQ*     2,4                                                  ID650180
        CAL*     2,4                                                  ID650190
        ADD*     3,4                                                  ID650200
        SLW*     2,4                                                  ID650210
 END    AXT      **,4                                                 ID650220
        TRA*     ID650                                                ID650230
           LITERALS

        END                                                           ID650240
```

```
**
**    MAP SUBROUTINE WHICH UNLOADS SPORT OUTPUT TAPES. T O ELSETHAGEN
**
      ENTRY  UNLOAD
**
UNLOAD PZE   **
      SXA    X4,4                 SAVE INDEX REGISTER 4
      LAC    UNLOAD,4
      CLA*   2,4                  PICKUP FORTRAN FILE NUMBER
      LAS    NFILES               IS FORTRAN FILE NUMBER GT. 11
      TRA    STOP1                YES
      NOP
      PAC    ,4                   NO
      CLA    TABLE,4              PICKUP CORRECT BCD FILE NAME
      STO    TEMP
      TMI    STOP2                TRANSFER IF SYS. INPUT,OUTPUT,PUNCH
      LAC    S.SLOC+1,4           ADDRESS OF FILE CONTROL BLOCK IN XR4
      LXD    S.SLOC+1,2           DECREMENT OF FCB IN XR2
      CLA    17,4
      CAS    TEMP
      TRA    *+2
      TRA    FOUND                FOUND CORRECT FILE CONTROL BLOCK
      TXI    *+1,4,-19
      TIX    *-5,2,1
      TRA    STOP3                CANNOT FIND CORRECT FCB
FOUND PXA    ,4
      PAC    ,4
      SXA    TEMP1,4
      TSX    S.CLSE,4
TEMP1 PTW    **
X4    AXT    **,4
      TRA*   UNLOAD
*                 ************************************
*                 *  STORAGE AND TABLE OF FILES      *
*                 ************************************
STOP1 CLA    UNLOAD
      TSX    S.XOVA,4
      STO    FMT1+10
      TSX    STHIO.,4
      PZE    FIL06.
      PZE    FMT1
      TSX    FILIO.,4
      PZE
STOP2 CLA    UNLOAD
      TSX    S.XOVA,4
      STO    FMT2+10
```

```
         TSX     STHIO.,4                                               UNLD0460
         PZE     FIL06.                                                 UNLD0470
         PZE     FMT2                                                   UNLD0480
         TSX     FILIO.,4                                               UNLD0490
         PZE                                                            UNLD0500
STOP3    TSX     STHIO.,4                                               UNLD0510
         PZE     FIL06.                                                 UNLD0520
         PZE     FMT3                                                   UNLD0530
         TSX     FILIO.,4                                               UNLD0540
         PZE                                                            UNLD0550
FMT1     TSX     IOHHC.,4                                               UNLD0560
         PZE     36                                                     UNLD0570
         BCI     6,FILE NAME GT 11 ERROR LOCATION                       UNLD0580
         TRA     IOHEF.                                                 UNLD0590
FMT2     TSX     IOHHC.,4                                               UNLD0600
         PZE     54                                                     UNLD0610
         BCI     9, ATTEMPTING TO REWIND SYSTEM INPUT,OUTPUT,PUNCH      UNLD0620
         TRA     IOHEF.                                                 UNLD0630
FMT3     TSX     IOHHC.,4                                               UNLD0640
         PZE     41                                                     UNLD0650
         BCI     7,COULD NOT FIND CORRECT FILE CONTROL BLOCK            UNLD0660
TEMP     BSS     1                                                      UNLD0670
TABLE    BCI     1,FTC00.                                               UNLD0680
         BCI     1,FTC01.                                               UNLD0690
         BCI     1,FTC02.                                               UNLD0700
         BCI     1,FTC03.                                               UNLD0710
         BCI     1,FTC04.                                               UNLD0720
         MZE                                                            UNLD0730
         MZE                                                            UNLD0740
         MZE                                                            UNLD0750
         BCI     1,FTC08.                                               UNLD0760
         BCI     1,FTC09.                                               UNLD0770
```

```
        BCI       1,FTC10.                                                                  UNLD0780
        BCI       1,FTC11.                                                                  UNLD0790
NFILES  PZE       *-TABLE-1                                                                 UNLD0800
        EXTERN    STHIO.,IOHHC.,IOHEF.,FILIO.,FIL06.                                        UNLD0810
        EXTERN        S.SLOC    GENERATED
        EXTERN        S.CLSE    GENERATED
        EXTERN        S.XOVA    GENERATED
        END                                                                                 UNLD0820
D
```

```
**
**      MAP SUBROUTINE WHICH SETS UP TRANSFER TO THE NEXT PROBLEM IF
**      CERTAIN ERRORS OCCUR.   R L COATES
**
        EXTERN   READY
**
        ENTRY    SET
**
  SET   PZE      **
        SXA      SET1,4
        LAC      SET,4
        CLA*     2,4
        ADD      SET
        STO      NO
        CALL     READY(NO)
 SET1   AXT      **,4
        TRA*     SET
  NO    BSS      1
        END
```

UPDATE PROCEDURE USED TO OBTAIN MODIFIED
XEM FOR USE WITH SUBROUTINE 'SET'

```
$PAUSE                MOUNT REEL NO. 348 ON S.SU05, SCRATCH ON S.SU07
$EXECUTE              UPDATE
$RUN EXTRACT
$LOCATE XEM
        ENTRY         READY                                           FTL22590
 READY  PZE           **                                              FTL22680
        SXA           *+4,4                                           FTL22681
        LAC           READY,4                                         FTL22682
        CLA*          2,4                                             FTL22683
        STA           OPEXIT                                          FTL22684
        AXI           **,4                                            FTL22685
        TRA*          READY                                           FTL22686
$DELETE FTL22760
 CELL1  OCT           +377777777777                                   FTL23890
 CELL2  OCT           +377777777777                                   FTL23910
$ENDRUN
$IBSYS
$IBJOB                NOGO
$IEDIT                U07,SRCH
$IBMAP XEM
$IEDIT
```

```
C       FORTRAN PROCESSING SUBROUTINE PROGRAM SMOOTH.
C
        SUBROUTINE SMOOTH(PART,ICODE,KSF,DT)
C
        COMMON DATA(2021),LDM,IFINC
        DIMENSION T(100),U(100),BUFF(600),STOR(400),
      1 HEAD(14),SCT(2),SCP(2),SSL(2)
        REAL MT1,MT2,MT3,MT4,M1,M2,M3,M4,M5,M6,MAG,L1,L2
        INTEGER CHNLNO,PCODE,PLCODE,PART
        LOGICAL SWTCH1,SWTCH2,SWTCH3,SWTCH4,SWTCH5,SWTCH6,SWTCH7,SWTCH8,
      1 SWTCH9,SWCH10,SWCH11,SWCH12,SWCH13,SWCH14,SWCH15
        EQUIVALENCE (DATA(1),T),(DATA(101),U),(DATA(201),BUFF),
      1 (DATA(801),STOR),(K,SWCH13)
C
C       READ SMOOTH TITLE CARD
C
        CALL TIMX(ITM)
        READ(5,1) HEAD
    1   FORMAT(13A6,1A2)
        LD=20000000002
        IBLANK=-17997958192
        IPASNO=1
   15   LDM=0
 1655   SCP(1)=1.0E+30
        SCP(2)=-1.0E+30
        SSL(1)=1.0E+30
        SSL(2)=-1.0E+30
        XLT=10.0
        XLP=7.0
C
C       READ SMOOTH CONTROL CARD
C
        READ(5,607)ND,NDL,DT,TO,TF,TRR,TRP,N,PCODE,PLCODE,IFORM,ISCAL,
      1 ORDER,IRECYL,ITRANS,ISAVE
  607   FORMAT(I9,A1,5E10.8,I2,8I1)
        CALL ID650(ND,NDL)
        REWIND 4
        READ(4) ID,CHNLNO,DT2
        IF(ICODE.EQ.5 .AND. CHNLNO.EQ.0) ND=ND/1000*1000
        CALL HEADER
        WRITE(6,2)
    2   FORMAT(1H0,28H QUADRATIC SMOOTHING PROGRAM78X,15H N L    S O R TO)
    5   WRITE(6,9)HEAD,IPASNO,ND,DT,TO,TF,TRR,TRP,N,PCODE,PLCODE,IFORM,
      1 ISCAL,ORDER,IRECYL,ITRANS,ISAVE
    9   FORMAT(107X15H U I PDC R  E RS/1X,13A6,1A2,26X15H M S LAA D C AM /
      1 107X,15H B T OTL E Y NN / 13H  PASS NUMBERI2,12X,6H ID NO,5X,8H D
      2ELTA T,6X,10H T MINIMUM,4X,10H T MAXIMUM,3X,28H T START CAL  1ST O
      3UTPUT T   15H R G TAE R L ST//26H  SMOOTH CONTROL CARD WAS-,I10,
      4 5F14.6,I3,2I2,2I1,3I2,I1,I3,I2,I3,I2 )
        IF(ID.EQ.ND)  GO TO 657
        WRITE(6,601) ID
  601   FORMAT(1H0,25H WRONG ID NUMBER DATA ID-I10 )
        N=-1
C
C       SET SMOOTH PARAMETERS
```

```
C                                                                       SMTH0550
  657 IF(TO.EQ.-0.0)  TO = -1.0E+28                                     SMTH0560
      IF(TF.EQ.-0.0)  TF = +1.0E+28                                     SMTH0570
      IF(DT.EQ.0.0)  DT=DT2                                             SMTH0580
      IF(ICODE.NE.5)  DT2=0.0                                           SMTH0590
      IF(IRECYL.LT.2) GO TO 1657                                        SMTH0600
 1557 SWTCH1=.TRUE.                                                     SMTH0610
      SWTCH2=.FALSE.                                                    SMTH0620
      SWTCH4=.FALSE.                                                    SMTH0630
      SWTCH8=.TRUE.                                                     SMTH0640
      SWTCH3=.TRUE.                                                     SMTH0650
 1558 TSR=TO                                                            SMTH0660
      TSP=TO                                                            SMTH0670
      GO TO 1659                                                        SMTH0680
 1657 IF(PCODE.EQ.1)  PUNCH 1,HEAD                                      SMTH0690
      TSP=TRP                                                           SMTH0700
      SWTCH1=PCODE.EQ.3                                                 SMTH0710
      SWTCH2=PCODE.EQ.1                                                 SMTH0720
      SWTCH3=PLCODE.EQ.0                                                SMTH0730
      SWTCH4=SWTCH3.AND.PART.EQ.1.AND.ITRANS.EQ.0                       SMTH0740
      SWTCH8=ISCAL.EQ.0                                                 SMTH0750
      SWCH14=PLCODE.LT.3                                                SMTH0760
 1658 TSR=TRR                                                           SMTH0770
 1659 TS=TSR                                                            SMTH0780
      K=-0                                                              SMTH0790
      K2=-3                                                             SMTH0800
      NCT=50                                                            SMTH0810
      IF(SWTCH4)  GO TO 923                                             SMTH0820
      REWIND 8                                                          SMTH0830
      WRITE(8) ND,CHNLNO,DT                                             SMTH0840
  923 IF(SWTCH8)  GO TO 924                                             SMTH0850
C                                                                       SMTH0860
C     READ IN SCALE FACTORS FOR PLOT                                    SMTH0870
C                                                                       SMTH0880
      READ(5,613) TMIN,TMAX,PMIN,PMAX,SMIN,SMAX,LT,LP                   SMTH0890
  613 FORMAT(6E10.3,2I2)                                                SMTH0900
      IF(LT.NE.0) XLT=LT                                                SMTH0910
      IF(LP.NE.0)  XLP=LP                                               SMTH0920
      DTM=(TMAX-TMIN)/XLT                                               SMTH0930
      DPR=(PMAX-PMIN)/XLP                                               SMTH0940
      DSR=(SMAX-SMIN)/XLP                                               SMTH0950
C                                                                       SMTH0960
  924 IF(N.LE.2)  GO TO 17                                              SMTH0970
      IF(((-1)**N).GT.0)  N=N-1                                         SMTH0980
      SWTCH5=INT(ABS(DT2-DT)*1.0E+7).EQ.0                               SMTH0990
  925 LL=N-1                                                            SMTH1000
      XN=N                                                              SMTH1010
      IF(SWTCH5)  DT=DT2                                                SMTH1020
      SWTCH6=.FALSE.                                                    SMTH1030
C                                                                       SMTH1040
C     FILL DATA ARRAY                                                   SMTH1050
C                                                                       SMTH1060
  710 READ(4) BUFF                                                      SMTH1070
      KR=-1                                                             SMTH1080
   10 KR=KR+2                                                           SMTH1090
```

```
      IF(KR.EQ.601)  GO TO 710                                          SMTH1100
      T(1)=BUFF(KR)                                                     SMTH1110
      IF(T(1).GT.TF)  GO TO 17                                          SMTH1120
      IF(T(1).LT.TO)  GO TO 10                                          SMTH1130
      U(1)=BUFF(KR+1)                                                   SMTH1140
      DO 30 I=2,N                                                       SMTH1150
   28 KR=KR+2                                                           SMTH1160
      IF(KR.LT.601)  GO TO 728                                          SMTH1170
      READ(4) BUFF                                                      SMTH1180
      KR=-1                                                             SMTH1190
      GO TO 28                                                          SMTH1200
  728 T(I)=BUFF(KR)                                                     SMTH1210
      IF(T(I).GT.TF)  GO TO 17                                          SMTH1220
      IF(T(I).LE.T(I-1)) GO TO 55                                       SMTH1230
      TIME=T(I)                                                         SMTH1240
   30 U(I)=BUFF(KR+1)                                                   SMTH1250
      I1=(N-1)/2                                                        SMTH1260
      I2=(N+1)/2                                                        SMTH1270
      I3=(N+3)/2                                                        SMTH1280
C                                                                       SMTH1290
C     READ IN DATA UNTIL SMOOTHING CAN BEGIN AT T = TSR                 SMTH1300
C                                                                       SMTH1310
  110 TEMP=(T(I1)+T(I2))*0.5                                            SMTH1320
      IF(SWTCH5 .OR. IRECYL.LT.2) GO TO 111                             SMTH1330
      TS=TRR-FLOAT(INT((TRR-TEMP)/DT))*DT                               SMTH1340
      IF(TS.LT.TEMP) TS=TS+DT                                           SMTH1350
      TSR=TS                                                            SMTH1360
      TSP=TS                                                            SMTH1370
  111 IF(TS-TEMP) 50,70,60                                              SMTH1380
C                                                                       SMTH1390
C     RESET TSR TO MIN ACCEPTABLE VALUE RETAINING ORIG TIMESHIFT        SMTH1400
C                                                                       SMTH1410
   50 IF(SWTCH5)  GO TO 70                                              SMTH1420
      TSP=TSP-TSR+TEMP                                                  SMTH1430
      TSR=TEMP                                                          SMTH1440
      TS=TEMP                                                           SMTH1450
      WRITE(6,612) TSR,TSP                                              SMTH1460
  612 FORMAT(1H ,25H CONTROL WORDS RESET      -,52X,2F14.6)             SMTH1470
      GO TO 70                                                          SMTH1480
C                                                                       SMTH1490
C     READ IN ANOTHER DATA VALUE                                        SMTH1500
C                                                                       SMTH1510
   41 KR=KR+2                                                           SMTH1520
      IF(KR.LT.601)  GO TO 741                                          SMTH1530
      READ(4) BUFF                                                      SMTH1540
      KR=1                                                              SMTH1550
  741 T(N)=BUFF(KR)                                                     SMTH1560
      IF(T(N).LE.T(N-1)) GO TO 55                                       SMTH1570
      TIME=T(N)                                                         SMTH1580
      IF(TIME.GT.TF) GO TO 841                                          SMTH1590
      U(N)=BUFF(KR+1)                                                   SMTH1600
      GO TO 60                                                          SMTH1610
C                                                                       SMTH1620
C     ERROR RETURNS                                                     SMTH1630
C                                                                       SMTH1640
```

```
   55 WRITE(6,56) TIME
   56 FORMAT(1H041H TIME SEQUENCE ERROR IN INPUT DATA AT T =F12.6 )
   17 LOM=1
C
C      NORMAL RETURN
C
  841 IF(SWTCH4)  GO TO 3842
      IF(IPASNO.LT.IRECYL) GO TO 6080
 6841 WRITE(8) STOR
      IF(ITRANS.EQ.0) GO TO 3842
C
C      TRANSFER SMOOTHED DATA TO OUTPUT TAPE
C
      REWIND 8
      IF(ITRANS.EQ.1) REWIND 9
      READ(8) ND,CHNLNO,DT
      WRITE(9) ND,CHNLNO,DT,K
      NORECS=(K-1)/100+1
      DO 3843 J=1,NORECS
      READ(8)  STOR
 3843 WRITE(9) STOR
      WRITE(6,3845)
 3845 FORMAT(1H0,41H SMOOTHED DATA TRANSFERRED TO OUTPUT TAPE )
      IF(ISAVE.EQ.0)  GO TO 3842
C
C      UNLOAD OUTPUT TAPE
C
      WRITE(9) LD,CHNLNO,DT,K
      END FILE 9
      CALL UNLOAD(9)
      CALL TYPE(1H ,1,0)
      CALL TYPE(38H   REMOVE DATA TAPE GENERATED ON T,8,6,38,0)
      CALL TYPE(28H        AND RECORD REEL NUMBER,28,0)
      WRITE(6,3846)
 3846 FORMAT(1H0,21H OUTPUT TAPE UNLOADED )
C
C      END OF CALCULATIONS
C
 3842 CALL ETIMX(ITM,ICALM,RCALS)
      IF(.NOT.SWTCH3 .AND. K.GT.25) GO TO 800
      WRITE(6,609) ICALM,RCALS
  609 FORMAT(1H0,27H CALCULATIONS REQUIRED     I4,5H MIN F4.1,4H SECA1,
     1 17HAND PLOT REQUIREDI3,5H MIN F4.1,4H SEC )
  842 IF(IPASNO.LT.IRECYL)  GO TO 4090
      KSF=K
      RETURN
C
C      TRANSFER OUTPUT TO S.SU04 FOR RESMOOTHING
C
 4090 IF(K.GT.0)  GO TO 5000
      K=-K
      LOM=1
      IF(K.LT.50)  K=0
 5000 REWIND 8
      READ(8) ND,CHNLNO
```

```
      REWIND 4
 6050 WRITE(4) ND,CHNLNO,DT
C
      NOCR04=K/300
      NOCR08=K/100
      IF(NOCR04.EQ.0)  GO TO 5001
      IEND=600
      GO TO 5004
C
 5001 IEND=(NOCR08-NOCR04*3)*200
      IF(IEND.EQ.0)  GO TO 5002
      J=0
      GO TO 5009
C
 5002 ISTART=-199
 5003 ISTART=ISTART+200
      IDONE=ISTART+(K-NOCR08*100)*2-1
      BUFF(IDONE+1)=1.0E+30
      IEND=0
      J=NOCR04+1
      IF(IDONE.GT.ISTART)  GO TO 5012
      GO TO 5013
C
 5004 J=0
 5005 J=J+1
 5009 ISTART=-199
 5010 ISTART=ISTART+200
      IDONE=ISTART+199
 5012 READ(8) (BUFF(I),BUFF(I+1),B,B,I=ISTART,IDONE,2)
      IF(IDONE.LT.IEND)  GO TO 5010
      IF(J.EQ.0)  GO TO 5003
C
 5013 WRITE(4) BUFF
      IF(J.LT.NOCR04)  GO TO 5005
      IF(IEND.EQ.600)  GO TO 5001
C
      IPASNO=IPASNO+1
      REWIND 4
      READ(4) ID,CHNLNO,DT2
      WRITE(6,5017) IPASNO
 5017 FORMAT(1H0,11H BEGIN PASSI2)
      IF(IPASNO.EQ.IRECYL)  GO TO 1657
      GO TO 1558
C
C     CHECK TO SEE IF MORE DATA IS NEEDED TO CAL NEXT SMOOTHED VALUE
C
   60 TEMP=(T(I2)+T(I3))/2.
   61 IF(TS-TEMP)70,70,80
   80 ICNT=ICNT+1
      DO 90 I=1,LL
      T(I)=T(I+1)
   90 U(I)=U(I+1)
      GO TO 41
C
C     CALCULATE SMOOTH COEFFICIENTS
```

```
C
   70 IF(SWCH13)  GO TO 6060
 3070 K=K+1
      IF(.NOT.SWTCH5)  GO TO 970
C
C     EVEN TIME INCREMENT SMOOTHING SECTION
C
      IF(SWTCH6)  GO TO 71
      TSP=TSP-TSR+T(I2)
      TSR=T(I2)
      TS=TSR
      WRITE(6,612) TSR,TSP
  971 L1=DT*DT*FLOAT( (N*N-1)*N )/12.0
      L2=(DT**4)*FLOAT( (3*N**4-10*N*N+7)*N )/240.0
      XNC=(XN 0.9)*DT
      DETT=XN*L1*L2-L1*L1*L1
      A1=XN*L1/DETT
      B1=(XN*L2-L1*L1)/DETT
      C1=L1*L2/DETT
      C2=-L1*L1/DETT
      LQ=N+1
      HFDT=DT*0.5
      QDTS=HFDT*HFDT
      SWTCH6=.TRUE.
   71 IF(T(N)-T(1) .GT. XNC)  GO TO 970
   72 F0=0.0
      F1=0.0
      F2=0.0
      DO 73 I=1,I1
      L=LQ-I
      SX=LQ-2*I
      F1=F1+(U(L)-U(I))*SX
   73 F2=F2+(U(L)+U(I))*SX*SX
      DO 74 I=1,N
   74 F0=F0+U(I)
      F1=F1*HFDT
      F2=F2*QDTS
      C=C1*F0+C2*F2
      B=B1*F1
      A=C2*F0+A1*F2
      GO TO 75
C
C     SAVE INITIAL VALUES FOR RECYCLING
C
 6060 IF(IPASNO.GE.IRECYL) GO TO 3070
      TMSHFT=TSP-TSR
      DO 6070  J2=1,I1
      K2=K2+4
      STOR(K2)=T(J2)+TMSHFT
      STOR(K2+1)=U(J2)
 6070 STOR(K2+2)=1.5E+30
      KADDTO=I1
      GO TO 3070
C
C     SAVE FINAL VALUES FOR RECYCLING
```

```
C
 6080  NRL=N
       IF(TIME.LT.TF)  GO TO 6081
       I3=I2
       NRL=N-1
 6081  DO 6090 J2=I3,NRL
       K2=K2+4
       STOR(K2)=T(J2)+TMSHFT
       STOR(K2+1)=U(J2)
       STOR(K2+2)=1.5E+30
       IF(K2.LT.397)  GO TO 6090
       WRITE(8) STOR
       K2=-3
 6090  CONTINUE
       WRITE(8) STOR
       K=K+KADDTO+N-I2
       GO TO 3842
C
C      UNEVEN TIME INCREMENT SMOOTHING SECTION
C
  970  DO 140 I=1,N
  140  T(I)=T(I)-TS
       FO=0.
       FT=0.
       FT2=0.
       MT1=0.
       MT2=0.
       MT3=0.
       MT4=0.
       DO 120 I=1,N
       MT1 = MT1 + T(I)
       XT2 = T(I) * T(I)
       MT2 = MT2 + XT2
       XT3 = XT2 * T(I)
       MT3 = MT3 + XT3
       XT4 = XT3 * T(I)
       MT4 = MT4 + XT4
       FO = FO + U(I)
       FT = FT + U(I) * T(I)
  120  FT2 = FT2 + U(I) * XT2
       DET =XN*(MT2*MT4 - MT3*MT3) - MT1*(MT1*MT4 - MT3*MT2)
      1 + MT2*(MT1*MT3 - MT2*MT2)
       M1 = (MT2*MT4 - MT3*MT3)/DET
       M2 =-(MT1*MT4 - MT2*MT3)/DET
       M3 = (MT1*MT3 - MT2*MT2)/DET
       M4 = (XN*MT4 - MT2*MT2)/DET
       M5 =-(XN*MT3 - MT1*MT2)/DET
       M6 = (XN*MT2 - MT1*MT1)/DET
       C = FO*M1 + FT*M2 + FT2*M3
       B = FO*M2 + FT*M4 + FT2*M5
       A = FO*M3 + FT*M5 + FT2*M6
  149  DO 150 I = 1, N
  150  T(I) = T(I) + TS
C
C      PRINT, PUNCH AND STORE SMOOTHED VALUE
```

```
C                                                                       SMTH3850
   75 TSO=TSP+FLOAT(K-1)*DT                                             SMTH3860
      IF(SWTCH1)  GO TO 929                                             SMTH3870
      NCT=NCT+1                                                         SMTH3880
      IF(NCT.GT.50)  GO TO 35                                           SMTH3890
   29 WRITE(6,605) ID,TSO,C,B,A                                         SMTH3900
  605 FORMAT(1X,I10,F14.6,3F16.7,3(2X,1PE14.7))                         SMTH3910
 2030 IF(SWTCH2) PUNCH 604,ID,TSO,C,B,A                                 SMTH3920
  604 FORMAT(I10,F16.6,3F16.7)                                          SMTH3930
      IF(SWTCH4)  GO TO 151                                             SMTH3940
  929 K2=K2+4                                                           SMTH3950
      STOR(K2)=TSO                                                      SMTH3960
      STOR(K2+1)=C                                                      SMTH3970
      STOR(K2+2)=B                                                      SMTH3980
      STOR(K2+3)=A                                                      SMTH3990
  915 IF(K2.LT.397)  GO TO 151                                          SMTH4000
      WRITE(8) STOR                                                     SMTH4010
      K2=-3                                                             SMTH4020
      IF(SWTCH3)  GO TO 151                                             SMTH4030
      IF(SWTCH8 .OR. DPR.EQ.0.0)  CALL MAXMIN(SCP,STOR,2,400,4)         SMTH4040
      IF(.NOT.SWCH14 .AND. (SWTCH8.OR.DSR.EQ.0.0))                      SMTH4050
     1 CALL MAXMIN(SSL,STOR,3,400,4)                                    SMTH4060
C                                                                       SMTH4070
C     RESET TS AND START NEXT SMOOTH CALCULATION                        SMTH4080
C                                                                       SMTH4090
  151 TS=TSR+FLOAT(K)*DT                                                SMTH4100
      GO TO 61                                                          SMTH4110
C                                                                       SMTH4120
C     WRITE PAGE HEADING                                                SMTH4130
C                                                                       SMTH4140
   35 CALL HEADER                                                       SMTH4150
      WRITE(6,7) CHNLNC                                                 SMTH4160
    7 FORMAT(1H0,42H SMOOTH PROGRAM OUTPUT LISTING FOR CHANNELI4 / )    SMTH4170
      WRITE(6,606)                                                      SMTH4180
  606 FORMAT(1H ,21H ID NUMBER       TIME,12X,2H C,14X,2H B,14X,2H A /)SMTH4190
      NCT=1                                                             SMTH4200
      GO TO 29                                                          SMTH4210
C                                                                       SMTH4220
C     PLOT SMOOTH COEFFICIENTS B AND C                                  SMTH4230
C                                                                       SMTH4240
  800 IRPOS=0                                                           SMTH4250
      IF(SWCH14)  GO TO 874                                             SMTH4260
      PLCODE=PLCODE-2                                                   SMTH4270
      IRPOS=1                                                           SMTH4280
  874 SCT(1)=TSP                                                        SMTH4290
      SCT(2)=TSO                                                        SMTH4300
  875 IF(IFORM.LT.2)  PLCODE=PLCODE+2                                   SMTH4310
      IF(SWTCH8)  GO TO 877                                             SMTH4320
      NCT=0                                                             SMTH4330
      IF(.NOT.SWTCH1) CALL HEADER                                       SMTH4340
  876 WRITE(6,614) TMIN,TMAX,PMIN,PMAX,SMIN,SMAX,LT,LP                  SMTH4350
  614 FORMAT(1H0,24H PLOT SCALING CARD WAS -2F14.6,4F16.8,2I2)          SMTH4360
C                                                                       SMTH4370
C     COEFFICIENT C                                                     SMTH4380
C                                                                       SMTH4390
```

```
  877 CALL DRAW(IRPOS,1,PLCODE,K,100,4,SWTCH8,STOR,SCT,SCP,
     1 XLT,TMIN,DTM,XLP,PMIN,DPR,
     2 HEAD,20H    COEFFICIENT C     )
      IF(SWCH14)  GO TO 1802
C
C     COEFFICIENT B
C
      CALL DRAW(-2,2,2,K,100,4,SWTCH8,STOR,SCT,SSL,
     1 XLT,TMIN,DTM,XLP,SMIN,DSR,
     2 HEAD,20H    COEFFICIENT B     )
 1802 IF(IPASNO.LT.2)  GO TO 1924
C
      CALL SYMBLJ(-0.3,XLP -0.875,0.14,4HPASS,90.0,4)
      CALL NUMBER(-0.3,XLP -0.250,0.14,FLOAT(IPASNO),90.0,-1)
C
 1924 CALL ETIMX(ITM,IPLTM,RPLTS)
      WRITE(6,609) ICALM,RCALS,IBLANK,IPLTM,RPLTS
      GO TO 842
C
      END
```

```
C       FORTRAN PROCESSING SUBROUTINE PROGRAM REACTIVITY.
C
        SUBROUTINE REACT(K,D,FRCODE)
C
        COMMON DATA(2021),LOM,IFINC
        DIMENSION XL(50),T(50),A(50),XK1(50),XK2(50),XK3(50),E(50),
      1 W(50),HEAD(14),STOR(400),BUFF(600),SCT(2),SCP(2),SCR(2),SCE(2)
        EQUIVALENCE (DATA(1),XL),(DATA(51),T),(DATA(101),A),(DATA(151),
      1 XK1),(DATA(201),XK2),(DATA(251),XK3),(DATA(301),E),(DATA(351),W),
      2 (DATA(401),STOR),(DATA(801),BUFF),(DATA(2001),HEAD)
        INTEGER PCODE,PLCODE,CHNLNO,PPLOT,RPLOT,EPLOT,PLCODE,FRCODE
        LOGICAL SWTCH1,SWTCH2,SWTCH3,SWTCH4,SWTCH5,SWTCH6,SWTCH7
C
C       READ CONTROL CARDS
C
        CALL TIMX(ITM)
  101   READ(5,1)HEAD
    1   FORMAT(13A6,1A2)
        READ(5,2) XLOB,AL,N,ICODE,PCODE,IECODE,PPLOT,RPLOT,EPLOT,ISCAL,
      1 ISAME,XE,SOURCE
    2   FORMAT(2E10.8,I2,8I1,2E10.8)
        IF(ISCAL.NE.0)READ(5,4003)TMINP,TMAXP,PMIN,PMAX,LTP,LPP,TMINR,
      1 TMAXR,RMIN,RMAX,LTR,LRR,TMINE,TMAXE,EMIN,EMAX,LTE,LEE
 4003   FORMAT(3(4E5.3,2I2,1X) )
  102   READ(5,3)(XL(I),I=1,N)
        READ(5,3)(A(I),I=1,N)
        IF(ICODE.NE.0)  READ(5,3)  (W(I),I=1,N)
    3   FORMAT(8E10.8)
        IF(K.EQ.0)  RETURN
C
C       READ IN FIRST DATA RECORD AND WRITE HEADING
C
        REWIND 8
        READ(8)ID,CHNLNO
        CALL HEADER
        WRITE(6,6) HEAD,XLOB,AL,N,ICODE,PCODE,IECODE,PPLOT,RPLOT,EPLOT,
      1 ISCAL,ISAME,XE,SOURCE
    6   FORMAT(1H0,19H REACTIVITY PROGRAM,61X,15H DG P L I PRE S /
      1 81X,15H ER C I N WTN C / 81X,15H LO    S T     A / 1X,13A6,1A2,
      2  15H AU C T    PPP L / 81X,15H YP O N E LLL E / 25X,18H LAMBDA / B
      3ETA BAR,5X,33H INITIAL AVERAGE RECIPR. PERIOD   ,42H PS N G N TTT S
      4  INITIAL ENERGY     SOURCE // 19H  CONTROL CARD WAS-F22.8,F30.8,
      5 I13,4I2,2I1,I2,I1,F15.8,F16.8 )
C
C       SET LOGICAL SWITCHES AND INTERNAL CONSTANTS
C
        SWTCH1=PCODE.EQ.3
        SWTCH2=PCODE.EQ.1
        SWTCH3=PPLOT+RPLOT+EPLOT.EQ.0
        SWTCH5=K.LT.0
        SWTCH4=SWTCH3 .AND. (SWTCH5.OR.FRCODE.EQ.0)
        SWTCH6=ISCAL.EQ.0
        SWTCH7=SOURCE.NE.0.0
        IBLANK=-17997958192
        IAXIS=0
```

```
      SCP(1)=1.0E+30                                                    REAC0550
      SCP(2)=-1.0E+30                                                   REAC0560
      SCR(1)=1.0E+30                                                    REAC0570
      SCR(2)=-1.0E+30                                                   REAC0580
      XLTP=10.0                                                         REAC0590
      XLTR=10.0                                                         REAC0600
      XLTE=10.0                                                         REAC0610
      XLPP=7.0                                                          REAC0620
      XLRR=7.0                                                          REAC0630
      XLEE=7.0                                                          REAC0640
      IF(SWTCH4)  GO TO 4020                                            REAC0650
      REWIND 4                                                          REAC0660
      WRITE(4) ID,CHNLNO,D,K                                            REAC0670
 4020 IF(SWTCH5)  K=-K                                                  REAC0680
      IF(SWTCH2)  PUNCH 1,HEAD                                          REAC0690
      IF(SWTCH6)  GO TO 4021                                            REAC0700
C                                                                       REAC0710
C     COMPUTE PLOT PARAMETERS                                           REAC0720
C                                                                       REAC0730
      IF(LTP.NE.0)  XLTP=LTP                                            REAC0740
      IF(LTR.NE.0)  XLTR=LTR                                            REAC0750
      IF(LTE.NE.0)  XLTE=LTE                                            REAC0760
      IF(ISAME.EQ.0)  GO TO 4007                                        REAC0770
      XLTP=AMAX1(XLTP,XLTR,XLTE)                                        REAC0780
      XLTR=XLTP                                                         REAC0790
      XLTE=XLTP                                                         REAC0800
      TMAXP=AMAX1(TMAXP,TMAXR,TMAXE)                                    REAC0810
      TMAXR=TMAXP                                                       REAC0820
      TMAXE=TMAXP                                                       REAC0830
      TMINP=AMIN1(TMINP,TMINR,TMINE)                                    REAC0840
      TMINR=TMINP                                                       REAC0850
      TMINE=TMINP                                                       REAC0860
 4007 IF(LPP.NE.0)  XLPP=LPP                                            REAC0870
      IF(LRR.NE.0)  XLRR=LRR                                            REAC0880
      IF(LEE.NE.0)  XLEE=LEE                                            REAC0890
      DTMP=(TMAXP-TMINP)/XLTP                                           REAC0900
      DTMR=(TMAXR-TMINR)/XLTR                                           REAC0910
      DTME=(TMAXE-TMINE)/XLTE                                           REAC0920
      DPR=(PMAX-PMIN)/XLPP                                              REAC0930
      DRT=(RMAX-RMIN)/XLRR                                              REAC0940
      DEX=(EMAX-EMIN)/XLEE                                              REAC0950
      WRITE(6,4008)TMINP,TMAXP,PMIN,PMAX,LTP,LPP,TMINR,TMAXR,RMIN,RMAX,REAC0960
     1 LTR,LRR,TMINE,TMAXE,EMIN,EMAX,LTE,LEE                            REAC0970
 4008 FORMAT(1H0,6X,29H SCALE FACTORS FOR POWER PLCT,12X,34H SCALE FACTREAC0980
     1ORS FOR REACTIVITY PLOT ,10X,30H SCALE FACTORS FOR ENERGY PLOT // REAC0990
     2 3(43H    T MIN     T MAX      MIN         MAX      X   Y)  //    REAC1000
     3 1X,1P3(4E9.2,2I3,1X) )                                           REAC1010
C                                                                       REAC1020
C     WRITE CONTROL CARDS                                               REAC1030
C                                                                       REAC1040
 4021 WRITE(6,612)                                                      REAC1050
  612 FORMAT(1H  /   59X,9H LAMBDA'S   /   )                            REAC1060
      WRITE(6 ,8)(XL(I),I=1,N)                                          REAC1070
    8 FORMAT(1H ,8F16.12)                                               REAC1080
      WRITE(6,613)                                                      REAC1090
```

```
  613 FORMAT(1H  /  59X,9H    F'S     /  )                                  REAC1100
      WRITE(6 ,8)(A(I),I=1,N)                                               REAC1110
      IF(ICODE.NE.0)  WRITE(6,614)                                          REAC1120
  614 FORMAT(1H  /  59X,9H    W'S     /  )                                  REAC1130
      IF(ICODE.NE.0)  WRITE(6,8)(W(I),I=1,N)                                REAC1140
      IF(SWTCH1)  GO TO 1234                                                REAC1150
 1233 CALL HEADER                                                           REAC1160
      WRITE(6,611) CHNLNO                                                   REAC1170
      WRITE(6,703)                                                          REAC1180
C                                                                           REAC1190
C     PRELIMINARY CALCULATIONS                                              REAC1200
C                                                                           REAC1210
 1234 DO 120 I=1,N                                                          REAC1220
      T(I)=XL(I)*D                                                          REAC1230
      SUM=T(I)                                                              REAC1240
      SUM1=T(I)                                                             REAC1250
      TEMP=T(I)                                                             REAC1260
      Z=1.0                                                                 REAC1270
   11 Z=Z+1.0                                                               REAC1280
      TEMP=TEMP*T(I)/Z                                                      REAC1290
      SUM=SUM-TEMP                                                          REAC1300
      Z=Z+1.0                                                               REAC1310
      TEMP=TEMP*T(I)/Z                                                      REAC1320
      SUM=SUM+TEMP                                                          REAC1330
      IF(SUM - SUM1 - 0.00001) 20, 20, 10                                   REAC1340
   10 SUM1=SUM                                                              REAC1350
      GO TO 11                                                              REAC1360
   20 XK3(I)=SUM                                                            REAC1370
      TEMP=-0.5*T(I)*T(I)                                                   REAC1380
      SUM1=TEMP                                                             REAC1390
      SUM=TEMP                                                              REAC1400
      Z=2.0                                                                 REAC1410
   30 Z=Z+1.0                                                               REAC1420
      TEMP=TEMP*T(I)*(Z-1.0)/(Z*Z-2.0*Z)                                    REAC1430
      SUM=SUM-TEMP                                                          REAC1440
      Z=Z+1.0                                                               REAC1450
      TEMP=TEMP*T(I)*(Z-1.0)/(Z*Z-2.0*Z)                                    REAC1460
      SUM=SUM+TEMP                                                          REAC1470
      IF (SUM - SUM1 + 0.00001) 40, 50, 50                                  REAC1480
   40 SUM1=SUM                                                              REAC1490
      GO TO 30                                                              REAC1500
   50 XK2(I)=SUM/XL(I)                                                      REAC1510
      TEMP=-T(I)*T(I)*T(I)/3.0                                              REAC1520
      SUM=TEMP                                                              REAC1530
      SUM1=TEMP                                                             REAC1540
      Z=2.0                                                                 REAC1550
   60 Z=Z+1.0                                                               REAC1560
      TEMP=TEMP*T(I)*Z/(Z*Z-Z-2.0)                                          REAC1570
      SUM=SUM-TEMP                                                          REAC1580
      Z=Z+1.0                                                               REAC1590
      TEMP=TEMP*T(I)*Z/(Z*Z-Z-2.0)                                          REAC1600
      SUM=SUM+TEMP                                                          REAC1610
      IF (SUM - SUM1 + 0.00001)70, 80, 80                                   REAC1620
   70 SUM1=SUM                                                              REAC1630
      GO TO 60                                                              REAC1640
```

```
   80 XK1(I)=-SUM/(XL(I)*XL(I))
  120 CONTINUE
C
C     FINAL CALCULATIONS FOR FIRST OUTPUT POINT
C
      READ(8) STOR
      TIME=STOR(1)
      C=STOR(2)
      B=STOR(3)
      XA=STOR(4)
      CLIN=EXP(C)
      SUM = 0.0
      DO 200 I=1,N
      TEMP=A(I)/(XL(I)+AL)
      SUM=SUM+TEMP
  200 CONTINUE
      DOLTO=AL*(XLOB+SUM)
      IF(IECODE.EQ.0 .AND. AL.NE.0.0)  XE=CLIN/AL
      DOLTC=0.0
      BTO=0.0
      NCT=1
C
C     PRINT FIRST OUTPUT POINT
C
      IF(PCODE.NE.3)  WRITE(6,5)  ID,TIME,CLIN,DOLTO,DOLTC,XE,BTO
      IF(PCODE.EQ.1) PUNCH 600,ID,TIME,CLIN,DOLTO,DOLTC,XE,BTO
      IF(SWTCH4)  GO TO 4323
C
C     STORE FIRST OUTPUT POINT
C
      BUFF(1)=TIME
      BUFF(2)=CLIN
      BUFF(3)=DOLTO
      BUFF(4)=DOLTC
      BUFF(5)=XE
      BUFF(6)=BTO
      SCT(1)=TIME
      SCE(1)=XE
      K3=1
C
C     CALCULATE W'S AND E'S
C
 4323 IF(ICODE.NE.0) GO TO 4322
      DO 4324 I=1,N
 4324 W(I)=XL(I)*CLIN/(XL(I)+AL)
 4322 DO 90 I=1,N
   90 E(I)=EXP(-T(I))
      K2=1
C
C     MAIN LOOP
C
      DO 100 M=2,K
C
C     LOCATE DATA NEEDED
C
```

```
      K2=K2+4
      IF(K2.LT.400)  GO TO 3090
      READ(8) STOR
      K2=1
 3090 TIME=STOR(K2)
      C=STOR(K2+1)
      B=STOR(K2+2)
      XA=STOR(K2+3)
C
C     FINAL CALCULATIONS
C
  500 CLIN=EXP(C)
      BLIN=B*CLIN
      ALIN=CLIN*(XA+0.5*B*B)
      XE=((0.333333333*ALIN*D-0.5*BLIN)*D+CLIN)*D+XE
      SUM=0.0
      DO 110 I=1,N
      W(I)=W(I)*E(I)+ALIN*XK1(I)+BLIN*XK2(I)+CLIN*XK3(I)
  110 SUM=SUM+W(I)*A(I)
      IF(SWTCH7)  B=B-SOURCE/CLIN
      DOLS=1.0+(XLOB*B-SUM/CLIN)
      DOLC=DOLS-DOLTO
      BT=DOLC/XE
      IF(SWTCH1)  GO TO 925
C
C     PRINT OUTPUT VALUES
C
      NCT=NCT+1
      IF(NCT-51)25,26,26
   25 WRITE(6,5)ID,TIME,CLIN,DOLS,DOLC,XE,BT
    5 FORMAT(2X,I10,F14.6,F16.4,2F16.7,F16.6,F16.10 )
      IF(SWTCH2)  PUNCH 600,ID,TIME,CLIN,DOLS,DOLC,XE,BT
  600 FORMAT(I10,F10.6,F12.4,2F12.6,F12.4,F12.8)
      IF(SWTCH4)  GO TO 100
C
C     STORE OUTPUT VALUES
C
  925 K3=K3+6
      BUFF(K3)=TIME
      BUFF(K3+1)=CLIN
      BUFF(K3+2)=DOLS
      BUFF(K3+3)=DOLC
      BUFF(K3+4)=XE
      BUFF(K3+5)=BT
      IF(K3.LT.595) GO TO 100
      WRITE(4) BUFF
      K3=-5
C
C     SCALE DATA POINTS IN ARRAY 'BUFF'
C
      IF(SWTCH3)  GO TO 100
      IF((PPLOT.NE.0).AND.(SWTCH6.OR.(DPR.EQ.0.0)))
     1  CALL MAXMIN(SCP,BUFF,2,600,6)
      IF((RPLOT.NE.0).AND.(SWTCH6.OR.(DRT.EQ.0.0)))
     1  CALL MAXMIN(SCR,BUFF,3,600,6)
```

```
      GO TO 100
C
C     WRITE PAGE HEADING
C
   26 CALL HEADER
      WRITE(6,611) CHNLNO
  611 FORMAT(1H0,46H REACTIVITY PROGRAM OUTPUT LISTING FOR CHANNELI4 /)
  702 WRITE(6,703)
  703 FORMAT(1X,11H RECORD NO.,4X,5H TIME12X,6H POWER,9X,26H REACTIVITY
     1  COMP. REACT.,6X,7H ENERGY,8X,5H B(T) / )
      NCT=1
      GO TO 25
  100 CONTINUE
C
C     END OF CALCULATIONS
C
      IF(.NOT.SWTCH4) WRITE(4) BUFF
      CALL ETIMX(ITM,ICALM,RCALS)
      IF(.NOT.SWTCH3) GO TO 7000
      WRITE(6,615) ICALM,RCALS
  615 FORMAT(1H0,27H CALCULATIONS REQUIRED     I4,5H MIN F4.1,4H SECA1,
     1 20HAND PLOT(S) REQUIREDI3,5H MIN F4.1,4H SEC )
      GO TO 3000
C
C     PLOT SECTION
C
 7000 SCT(2)=TIME
      IF(PPLOT+RPLOT.EQ.0)  GO TO 7005
      IF(PPLOT.EQ.0)  GO TO 7002
C
C     PLOT POWER
C
      IF(ISAME.NE.0)  IAXIS=IAXIS+1
      CALL DRAW(IAXIS,1,PPLOT,K,100,6,SWTCH6,BUFF,SCT,SCP,
     1 XLTP,TMINP,DTMP,XLPP,PMIN,DPR,
     2 HEAD,20HREACTOR POWER   (MW) )
      IF(RPLOT.EQ.0)  GO TO 7003
C
C     PLOT REACTIVITY
C
 7002 IF(ISAME.NE.0)  IAXIS=IAXIS+1
      IF(EPLOT.EQ.0)  IAXIS=-IAXIS
      CALL DRAW(IAXIS,2,RPLOT,K,100,6,SWTCH6,BUFF,SCT,SCR,
     1 XLTR,TMINR,DTMR,XLRR,RMIN,DRT,
     2 HEAD,20HREACTIVITY (DOLLARS) )
 7003 IF(EPLOT.EQ.0)  GO TO 7006
C
C     PLOT ENERGY
C
 7005 SCE(2)=XE
      IF(ISAME.NE.0)  IAXIS=-IAXIS-1
      CALL DRAW(IAXIS,4,EPLOT,K,100,6,SWTCH6,BUFF,SCT,SCE,
     1 XLTE,TMINE,DTME,XLEE,EMIN,DEX,
     2 HEAD,20H  ENERGY  (MW-SEC)   )
C
```

```
 7006  CALL ETIMX(ITM,IPLTM,RPLTS)                                    REAC3300
       WRITE(6,615) ICALM,RCALS,IBLANK,IPLTM,RPLTS                     REAC3310
C                                                                     REAC3320
 3000  IF(SWTCH5) K=0                                                 REAC3330
       RETURN                                                         REAC3340
C                                                                     REAC3350
       END                                                            REAC3360
```

```
C       FORTRAN SUBROUTINE WHICH CONTROLS SPORT PLOTS.
C
        SUBROUTINE DRAW(IK,JX,PPLOT,K,NPR,ISKIP,SWTCH6,ARAY,SCT,SCP,
      1 XLTP,TMINP,DTMP,XLPP,PMIN,DPR,
      2 HEAD,LABEL )
C
        COMMON DATA(2021),LDM,IFINC,IPGNO,IHED(14),DATE(2)
        DIMENSION SCT(2),SCP(2),ARAY(2),BUFF(600),STOR(400),S2T(2),
      1 HEAD(14),LABEL(4),QJAN(2)
        EQUIVALENCE (DATA(1401),BUFF,STOR),(IFINC,SMALL1)
        LOGICAL SWTCH1,SWTCH2,SWTCH3,SWTCH4,SWTCH5,SWTCH6,SWTCH7,SWTCH8,
      1 SWTCH9,SMALL1,SMALL2
        INTEGER PPLOT,CHNLNO
C
        SWTCH5=IK.EQ.999
        SWTCH2=.NOT.SWTCH5 .AND. IK.GT.0
        I2=IABS(IK)
        SWTCH3=.NOT.SWTCH5 .AND. I2.GT.1
        SWTCH4=SWTCH5 .OR. I2.LT.7
        SWTCH9=SWTCH6 .OR. DPR.EQ.0.0
        XSTR=FLOAT(1-I2/5)*(XLTP+FLOAT(I2-1)*.5)+FLOAT((I2/5)*(4-I2))*.5
        IF(I2.LT.2 .OR. SWTCH5) XSTR=0.0
        IF(SWTCH3)  GO TO 6995
C
C       POSITION PLOT
C
        IF(IFINC.GT.0) GO TO 200
        IF(.NOT.SMALL1) GO TO 100
C
C       SET UP FOR SMALL PLOTTER
C
        SMALL2=.TRUE.
        CALL PLOTS(0.0,-2.0,-3)
        GO TO 200
C
  100   SMALL2=.FALSE.
        CALL PLOT(0.0,-2.0,-3)
  200   SWTCH1=SMALL2.OR.XLTP.GT.10.5.OR.XLPP.GT.7.5
        IFINC=IFINC+1
        ICOUNT=ICOUNT+1
        IF(IFINC.GT.1 .AND. ICOUNT.EQ.1)  GO TO 7000
        IF(IFINC.EQ.1)  ICOUNT=1
        XXX=0.0
        YYY=0.5
        IF(ICOUNT.EQ.1)  GO TO 7000
        ITEST=ICOUNT - (ICOUNT-1)/3*3 - 1
        YYY=10.0
        IF(ITEST.NE.0)  GO TO 6990
        XXX=15.0
        YYY=-20.0
 6990   IF(.NOT.SWTCH1)  GO TO 7000
        XXX=15.0
        YYY=YYY-FLOAT(ITEST)*10.0
 7000   CALL PLOT(XXX,YYY,-3)
C
```

```
C      SCALE DATA AND DRAW AXIS
C
 6995  IF(K.EQ.0)  RETURN
       K6=K/NPR
       K7=K-K6*NPR
       K8=K7*ISKIP
       S2T(1)=SCT(1)
       S2T(2)=SCT(2)
       IF(.NOT.SWTCH9) GO TO 830
       CALL MAXMIN(SCP,ARAY,1+JX,K8,ISKIP)
       IF(PPLOT.LT.3)  GO TO 830
       IF(SCP(1).LT.-88.0 .OR. SCP(2).GT.88.0)  GO TO 855
       SCP(1)=EXP(SCP(1))
       SCP(2)=EXP(SCP(2))
  830  IF((-1)**PPLOT.LT.0.AND.(SCP(1).GT.0..OR..NOT.SWTCH9)) GO TO 835
       IF(PPLOT.NE.1)  GO TO 831
       PPLOT=2
       IF(SWTCH9) GO TO 831
       SCP(1)=10.0**(SCP(1))
       SCP(2)=10.0**(SCP(2))
  831  IF(SWTCH9) CALL SCALE(SCP,2,XLPP,PMIN,DPR,1)
       IF(SWTCH4) CALL AXIS(XSTR,0.0,LABEL,20,XLPP,90.0,PMIN,DPR)
       GO TO 836
  835  IF(SWTCH9)CALL LSCALE(SCP,2,XLPP,PMIN,DPR,1)
       IF( SWTCH4)CALL LAXIS(XSTR,0.0,LABEL,20,XLPP,90.0,PMIN,DPR)
  836  IF(ISKIP.EQ.2)  GO TO 825
       IF(ISKIP.EQ.6)  GO TO 837
       REWIND 8
       READ(8) ID,CHNLNO
       GO TO 838
  837  REWIND 4
  825  READ(4) ID,CHNLNO
  838  IF(SWTCH5)  GO TO 870
       IF(SWTCH5 .OR. DTMP.EQ.0.0) CALL  SCALE(S2T,2,XLTP,TMINP,DTMP,1)
       IF(SWTCH3)  GO TO 839
       CALL AXIS(0.0,0.0,10HTIME (SEC),10,XLTP,0.0,TMINP,DTMP)
C
C      DRAW LINE
C
  839  JRK=MIN0(NPR*ISKIP,K*ISKIP-1)
       IPEN=3
       XLAST=0.0
       YLAST=0.0
       SWTCH5=.TRUE.
       SWTCH7=.FALSE.
  801  DO 815 I=0,K6
       IF(ISKIP.EQ.4)  READ(8) STOR
       IF(ISKIP.NE.4)  READ(4) BUFF
       IF(I.LT.K6)  GO TO 802
       IF(K7.EQ.0)  GO TO 815
       JRK=K8
  802  DO 815 J=1,JRK,ISKIP
       BUFF(J)=(BUFF(J)-TMINP)/DTMP
  804  JJJ=J+JX
       GO TO(806,807,808,809),PPLOT
```

```
  808 BUFF(JJJ)=(BUFF(JJJ)*0.43429448-PMIN)/DPR
      GO TO 810
  809 BUFF(JJJ)=EXP(BUFF(JJJ))
      GO TO 807
  806 BUFF(JJJ)=ALOG10(BUFF(JJJ))
  807 BUFF(JJJ)=(BUFF(JJJ)-PMIN)/DPR
  810 SWTCH8= BUFF(J).LT.0.0 .OR. BUFF(J).GT.XLTP
     1 .OR.  BUFF(JJJ).LT.0.0 .OR. BUFF(JJJ).GT.XLPP
      IF(.NOT.SWTCH7 .AND. .NOT.SWTCH8)  GO TO 813
      IF(SWTCH7.AND.SWTCH8)  GO TO 814
C
C     CURRENT OR PREVIOUS POINT OFF-SCALE
C
      GOODX=XLAST
      GOODY=YLAST
      BADX=BUFF(J)
      BADY=BUFF(JJJ)
      IF(.NOT.SWTCH7)  GO TO 811
      GOODX=BUFF(J)
      GOODY=BUFF(JJJ)
      BADX=XLAST
      BADY=YLAST
  811 XSUB=0.0
      YSUB=0.0
      IF(BADY.GT.GOODY) YSUB=XLPP
      IF(BADX.GT.GOODX) XSUB=XLTP
      SLOPE=1.0E+10
      IF(BADX.NE.GOODX) SLOPE=(BADY-GOODY)/(BADX-GOODX)
      BUFF(JJJ)=GOODY+(XSUB-GOODX)*SLOPE
      BUFF(J)=GOODX+(YSUB-GOODY)/SLOPE
      IF(BUFF(JJJ).GT.XLPP)  BUFF(JJJ)=XLPP
      IF(BUFF(JJJ).LT.0.0)  BUFF(JJJ)=0.0
      IF(BUFF(J).GT.XLTP)  BUFF(J)=XLTP
      IF(BUFF(J).LT.0.0)  BUFF(J)=0.0
      CALL PLOT(BUFF(J),BUFF(JJJ),IPEN)
      IF(SWTCH7)  GO TO 812
      IPEN=3
      SWTCH5=.TRUE.
      GO TO 814
  812 IPEN=0
      SWTCH5=.FALSE.
  813 CALL PLOT(BUFF(J),BUFF(JJJ),IPEN)
      IF(.NOT.SWTCH5)  GO TO 814
      IPEN=0
      SWTCH5=.FALSE.
  814 XLAST=BUFF(J)
      YLAST=BUFF(JJJ)
      SWTCH7=SWTCH8
  815 CONTINUE
      IF(SWTCH3)  GO TO 7200
C
C     DRAW LABELS
C
  870 CALL SYMBLJ(0.0,XLPP+0.05,AMIN1(0.014*XLTP,0.42),HEAD,0.0,80)
      CALL BBCD1(ID,QUAN(1),QUAN(2) )
```

```
      CALL SYMBLJ(-0.250,-0.46,0.14,QUAN,0.0,12)
      CALL SYMBLJ(-0.3,0.0,0.14,DATE,90.0,8)
      IF(CHNLNO.GT.0 .AND. CHNLNO.LT.7) CALL NUMBER(1.250,-0.44,0.14,
     1 -FLOAT(CHNLNO),0.0,-1)
 7200 IF(.NOT.SWTCH1 .OR. SWTCH2)  RETURN
C
C     REPOSITION PEN IF THIS PLOT WAS LARGER THAN 10 X 7
C
      ICOUNT=0
      XXX=XLTP+5.0
      YYY=0.0
      RETURN
C
C     ERROR RETURN
C
  055 WRITE(6,856)
  856 FORMAT(1H021H UNABLE TO SCALE DATA )
      RETURN
C
      END
```

```
C       FORTRAN PROCESSING SUBROUTINE PROGRAM FREQUENCY RESPONSE.
C
        SUBROUTINE FREQ(TART,ICODE,K,DELTA)
C
        COMMON DATA(2021),LOM,IFINC
        DIMENSION W(100),R(100),P(100),D(100),S(100),A(5),HEAD(14),
     1 X(100),Y(100),Z(100),STOR(400),BUFF(600),STOR2(400),LABELX(3)
        EQUIVALENCE (DATA(1),W),(DATA(101),R),(DATA(201),P),(DATA(301),D)
     1 ,(DATA(401),S),(DATA(501),A),(DATA(506),HEAD),(DATA(520),X),
     2 (DATA(620),Y),(DATA(720),Z),(DATA(820),STOR),(DATA(1220),BUFF,
     3 STOR2)
        REAL NUM
        INTEGER PLCODE,TART,CHNLNO,PCODE
        LOGICAL SWTCH1,SWTCH2,SWTCH3,SWTCH4,SWTCH5,SWTCH6,SWTCH7,SWTCH8
C
        CALL TIMX(ITM)
   400  READ(5,13)HEAD
    13  FORMAT(13A6,1A2)
        READ(5,10) N,I,J,L,PLCODE,PCODE,IWSCPS,ALPHA
    10  FORMAT(I3,6I1,11X,E10.8)
        READ(5,11)(W(M),M=1,N)
    11  FORMAT(8E10.8)
        IF(K.LE.0)  RETURN
        IF(N.EQ.0 .OR. I.EQ.0) RETURN
        K4=1
        IBLANK=-17997958192
        SWTCH1=PCODE.NE.0
        SWTCH2=TART.NE.3
        SWTCH3=TART.NE.5 .OR. ICODE.NE.5
        SWTCH4=ALPHA.NE.0.0
        SWTCH5=L.EQ.4
        SWTCH6=L.EQ.3
        SWTCH7=SWTCH5 .OR. SWTCH6
        SWTCH8=IWSCPS.NE.0
        IF(.NOT.SWTCH2)  GO TO 401
        REWIND 4
        READ(4)ID,CHNLNO
   401  CALL HEADER
        WRITE(6,14) HEAD
    14  FORMAT(1H0,27H FREQUENCY RESPONSE PROGRAM // 1X,13A6,1A2 / )
        IF(SWTCH1) PUNCH 13,HEAD
        WRITE(6,16) N,I,J,L,PLCODE,PCODE,IWSCPS,ALPHA
    16  FORMAT(1H ,18H CONTROL CARD WAS-,I3,I2,2I1,3I2,9H  ALPHA =F14.8)
        IF(.NOT.SWTCH8)  WRITE(6,18)
    18  FORMAT(1X/ 51X,19H RADIAN FREQUENCIES / )
        IF(SWTCH8) WRITE(6,4018)
  4018  FORMAT(1X/ 51X,19H FREQUENCIES IN CPS / )
        WRITE(6,17)(W(M),M=1,N)
    17  FORMAT(1H ,8F16.7)
        IF(.NOT.SWTCH2 .OR. (.NOT.SWTCH3)) L=2
        IF(SWTCH7) L=1
        HALFD=DELTA* .5
        T0=0.0
C
C       READ IN FIRST DATA POINT
```

```
C                                                                      FREQ0550
  800 IF(SWTCH2) GO TO 802                                              FREQ0560
  801 REWIND 8                                                          FREQ0570
      READ(8) ID,CHNLNO                                                 FREQ0580
      READ(8) STOR                                                      FREQ0590
      IF(SWTCH7)  GO TO 1801                                            FREQ0600
      AO=STOR(I+1)                                                      FREQ0610
      GO TO 703                                                         FREQ0620
 1801 REWIND 9                                                          FREQ0630
      READ(9) ND,INTWO,DTOK,KOK                                         FREQ0640
      READ(9) STOR2                                                     FREQ0650
      IF(KOK.LT.K) K=KOK                                                FREQ0660
      IF(INT((DELTA-DTOK)*1.0E+7).NE.0) GO TO 2005                      FREQ0670
      AO=STOR2(I+1)                                                     FREQ0680
      IF(SWTCH5)  AO=AO-STOR(I+1)                                       FREQ0690
      GO TO 777                                                         FREQ0700
 2005 WRITE(6,608)                                                      FREQ0710
  608 FORMAT(1H046H DELTA T'S WERE DIFFERENT FOR THE TWO CHANNELS    )  FREQ0720
      RETURN                                                            FREQ0730
  802 READ(4) BUFF                                                      FREQ0740
      IF(SWTCH3)  GO TO 803                                             FREQ0750
      AO=BUFF(2)                                                        FREQ0760
      GO TO 703                                                         FREQ0770
  803 AO=BUFF(I+1)                                                      FREQ0780
      IF(L.EQ.2)  GO TO 703                                             FREQ0790
  777 BO=BUFF(J+1)                                                      FREQ0800
      IF(SWTCH4)  BO=BO*EXP(-ALPHA*TO)                                  FREQ0810
C                                                                       FREQ0820
  703 IF(SWTCH4) AO=AO*EXP(-ALPHA*TO)                                   FREQ0830
      CALL TYPE(1H ,1,0)                                                FREQ0840
      CALL TYPE(36H PROGRAM NOW ENTERS LONG NORMAL LOOP,36,0)           FREQ0850
      GO TO (1,2),L                                                     FREQ0860
    1 DO 3 M=1,N                                                        FREQ0870
      IF(SWTCH8)  W(M)=W(M)*6.2831853072                                FREQ0880
      R(M)=0.                                                           FREQ0890
      D(M)=0.                                                           FREQ0900
      DEN=2.*SIN(W(M)*HALFD)                                            FREQ0910
      NUM=W(M)*DELTA                                                    FREQ0920
      P(M)=(AO*NUM)/DEN                                                 FREQ0930
    3 S(M)=(BO*NUM)/DEN                                                 FREQ0940
      GO TO 20                                                          FREQ0950
    2 DO 8 M=1,N                                                        FREQ0960
      IF(SWTCH8)  W(M)=W(M)*6.2831853072                                FREQ0970
      R(M)=0.                                                           FREQ0980
      S(M)=0.                                                           FREQ0990
      DEN=2.*SIN(W(M)*HALFD)                                            FREQ1000
      NUM=W(M)*DELTA                                                    FREQ1010
      P(M)=(AO*NUM)/DEN                                                 FREQ1020
    8 D(M)=-((W(M)*NUM)/DEN)                                            FREQ1030
   20 DO 19 NL=2,K                                                      FREQ1040
      T1=FLOAT(NL-1)*DELTA                                              FREQ1050
C                                                                       FREQ1060
C     READ IN ANOTHER DATA POINT                                        FREQ1070
C                                                                       FREQ1080
  810 IF(SWTCH2)  GO TO 812                                             FREQ1090
```

```
  811 K4=K4+4
      IF(K4.LT.400)  GO TO 3811
      READ(8) STOR
      IF(SWTCH7) READ(9) STOR2
      K4=1
 3811 II=K4+I
      IF(SWTCH7)  GO TO 1811
      A1=STOR(II)
      GO TO 713
 1811 A1=STOR2(II)
      IF(SWTCH5) A1=A1-STOR(II)
      GO TO 888
  812 K4=K4+2
      IF(SWTCH3) K4=K4+4
      IF(K4.LT.600)  GO TO 3812
      READ(4) BUFF
      K4=1
 3812 IF(SWTCH3) GO TO 813
      A1=BUFF(K4+1)
      GO TO 713
  813 II=K4+I
      A1=BUFF(II)
      IF(L.EQ.2)  GO TO 713
  888 IJ=K4+J
      B1=BUFF(IJ)
      IF(SWTCH4) B1=B1*EXP(-ALPHA*T1)
C
  713 IF(SWTCH4)  A1=A1*EXP(-ALPHA*T1)
      DIFA=A1-A0
      DIFB=B1-B0
      TIME=T0+HALFD
      GO TO (5,6),L
    5 DO 7 M=1,N
      AN=W(M)*TIME
      PART=SIN(AN)
      PART1=COS(AN)
      R(M)=R(M)+DIFA*PART
      P(M)=P(M)+DIFA*PART1
      D(M)=D(M)+DIFB*PART
    7 S(M)=S(M)+DIFB*PART1
   22 A0=A1
      B0=B1
      T0=T1
      GO TO 19
    6 DO 9 M=1,N
      AN=W(M)*TIME
      PART=SIN(AN)
      PART1=COS(AN)
      R(M)=R(M)+DIFA*PART
      P(M)=P(M)+DIFA*PART1
    9 CONTINUE
      GO TO 22
   19 CONTINUE
C
C     PRINT OUT RESULTS
```

```
C
      NCT=50
      IQC= -29809118256
      IQM=  -5113056304
      DO 41 M=1,N
      DEN = D(M)*D(M) + S(M)*S(M)
      REA =(R(M)*D(M)+P(M)*S(M))/DEN
      AGIN=(D(M)*P(M)-R(M)*S(M))/DEN
      CALL ANGRAD(REA,AGIN,G,ANG)
C
      IF(SWTCH8)  W(M)=W(M)*0.159154943
      X(M)=ALOG10(W(M))
C
      IF(G.EQ.0.0) G=1.0E-30
      Y(M)=20.0*ALOG10(G)
      Z(M)=ANG*57.2957795-360.0
C
      NCT=NCT+1
      IF(NCT.GT.45) GO TO 39
   40 WRITE(6,15) W(M),X(M),REA,AGIN,G,Z(M),Y(M)
   15 FORMAT(3X,F14.4,3X,F7.3,3(3X,1PE14.7),3X,0PF14.8,3X,0PF14.7)
      IF(SWTCH1)PUNCH 604,ID,W(M),REA,AGIN,Z(M),Y(M)
  604 FORMAT(I10,F14.4,1P2E14.7,0PF14.8,0PF14.7)
      GO TO 41
C
C     WRITE PAGE HEADING
C
   39 CALL HEADER
      IF(SWTCH7) GO TO 3039
      IF(L.EQ.1) WRITE(6,600) ID,CHNLNO,I,IQC,J
  600 FORMAT(1H0,11H RECORD NO I10,9H CHANNEL I3,5X,20H  NUMERATOR WAS
     1WORDI2,A1,21H DENOMINATOR WAS WORDI2 )
      IF(L.EQ.2) WRITE(6,600) ID,CHNLNO,I
      GO TO 3040
C
 3039 IF(SWTCH5)  WRITE(6,605) ND,INTWO,IQM,ID,CHNLNO
      IF(SWTCH6)  WRITE(6,605) ND,INTWO
  605 FORMAT(1H0,46H NUMERATOR  WAS  SMOOTHED DATA FROM RECORD NO I10,
     1 9H CHANNEL I3,1X,A1,34HINUS SMOOTHED DATA FROM RECORD NO I10,9H C
     2HANNEL I3 )
      WRITE(6,606) ID,CHNLNO
  606 FORMAT(1X/47H  DENOMINATOR WAS SMOOTHED DATA FROM RECORD NO I10,
     1 9H CHANNEL I3 )
C
 3040 IF(SWTCH8)  WRITE(6,3045)
 3045 FORMAT(1H019H FREQUENCIES IN CPS  )
      WRITE(6,601)
  601 FORMAT(15H0      FREQUENCY5X,6H LOG W4X,11H REAL G(IW),5X,12H IMA
     1G. G(IW),7X,7H MAG. G,8X,12H PHASE ANGLE,3X,15H 20 LOG(MAG. G) /)
      NCT=1
      GO TO 40
C
   41 CONTINUE
C
      CALL ETIMX(ITM,ICALM,RCALS)
```

```
      IF(PLCODE.GT.0) GO TO 7000
      WRITE(6,502) ICALM,RCALS
  602 FORMAT(1H0,27H CALCULATIONS REQUIRED       I4,5H MIN F4.1,4H SEC1,
     1 20HAND PLOT(S) REQUIREDI3,5H MIN F4.1,4H SEC )
      RETURN
C
C     PLOT SECTION
C
 7000 ITPORT=4
      IF(SWTCH2)  ITPORT=6
      CALL LSCALE(W,N,10.0,WMIN,DW,1)
C
C     MAGNITUDE PLOT
C
      LABELX(1)= -17559804468
      LABELX(2)=  23174548505
      LABELX(3)=  -6179159216
      IF(SWTCH8)  GO TO 7002
      LABELX(1)= -17872275025
      LABELX(2)=  -6179951976
      LABELX(3)= -21836938800
 7002 CALL SCALE(Y,N,7.0,YMIN,DY,1)
C
      CALL DRAW(999,1,2,N,100,ITPORT,.FALSE.,Y,R,P,
     1 10.0,WMIN,DW,7.0,YMIN,DY,
     2 HEAD,20HMAGNITUDE (DECIBELS) )
      DO 503 M=1,N
  503 CALL SYMBLJ(W(M)-0.03125,Y(M)-0.035,0.07,1H0,0.0,1)
      CALL LAXIS(0.0,0.0,LABELX,18,10.0,0.0,WMIN,DW)
      IF(PLCODE.EQ.1)  GO TO 2505
C
C     PHASE PLOT
C
 7003 CALL SCALE(Z,N,7.0,ZMIN,DZ,1)
C
      CALL DRAW(999,1,2,N,100,ITPORT,.FALSE.,Z,R,P,
     1 10.0,WMIN,DW,7.0,ZMIN,DZ,
     2 HEAD,20H   PHASE   (DEGREES)    )
      DO 505 M=1,N
  505 CALL SYMBLJ(W(M)-0.03125,Z(M)-0.035,0.07,1HX,0.0,1)
      CALL LAXIS(0.0,0.0,LABELX,18,10.0,0.0,WMIN,DW)
C
 2505 CALL ETIMX(ITM,IPLTM,RPLTS)
      WRITE(6,602) ICALM,RCALS,IBLANK,IPLTM,RPLTS
      RETURN
C
      END
```

```
C       FORTRAN SUBROUTINE WHICH READS CARD INPUT DIRECTLY INTO
C       PROCESSING PROGRAMS REACTIVITY AND FREQUENCY RESPONSE.
C
        SUBROUTINE INPUT(PART,ICODE,K,DT,IPNLST)
C
        COMMON DATA(2021)
        DIMENSION A4(4),B4(4),A6(6),B6(6),FMT(14),STOR(400),BUFF(600)
        EQUIVALENCE (DATA(1),A4,A6),(DATA(7),STOR),(DATA(407),BUFF)
        INTEGER PART,CHNLNO
        LOGICAL SWTCH1,SWTCH2
C
        CALL TIMX(ITM)
        READ(5,901) ID,IDL,DT
  901   FORMAT(I9,A1,E10.5)
        CALL ID650(ID,IDL)
  925   WRITE(6,13)ID,DT
   13   FORMAT(1H0,16H INPUT CARD WAS I10,F13.6)
        SWTCH1=IPNLST.EQ.0
        IF(SWTCH1) WRITE(6,813)
  813   FORMAT(1H0,16H LISTING DELETED )
C
        KX=0
        SWTCH2=.FALSE.
        INM=0
        CHNLNO=1
        IF(SWTCH1) GO TO 912
        CALL HEADER
        WRITE(6,913) ID
  913   FORMAT(1H0,45X,29H DATA READ IN  RECORD NUMBER I10 / )
  912   PART=PART-3
        GO TO(14,16),PART
   14   REWIND 8
        WRITE(8)ID,CHNLNO
        KS=-3
        GO TO 18
   16   REWIND 4
        WRITE(4)ID,CHNLNO
        KS=-5
   18   IF(ICODE.EQ.0) ICODE=1
        IF(ICODE.NE.4) GO TO 20
        READ(5,9)NOCHNL,FMT
    9   FORMAT(I1,13A6,1A1)
        DO 19 I=1,6
   19   A6(I)=0.0
C
C       READ DATA CARDS
C
   20   GO TO(100,200,300,400),ICODE
  100   GO TO(101,102),PART
  101   READ(5,2)ND,A4
    2   FORMAT(I10,4E16.9)
        GO TO 600
  102   READ(5,3)ND,A6
    3   FORMAT(I10,E10.8,5E12.9)
        GO TO 600
```

```
  200 GO TO (201,202),PART
  201 READ(5,4)ND,(A4(I),B4(I),I=1,4)
    4 FORMAT(I10,4(F8.8,A2))
      GO TO 344
  202 READ(5,5)ND,(A6(I),B6(I),I=1,6)
    5 FORMAT(I10,6(F8.8,A2))
  203 GO TO 346
  300 GO TO(301,302),PART
  301 READ(5,6)ND,NDL,(A4(I),B4(I),I=1,4)
    6 FORMAT(I9,A1,6(F8.8,A2))
      GO TO 344
  302 READ(5,6)ND,NDL,(A6(I),B6(I),I=1,6)
  346 CALL DAT650(A6,B6,6)
      GO TO 345
  344 CALL DAT650(A4,B4,4)
  345 CALL ID650(ND,NDL)
      GO TO 600
  400 GO TO(401,402),PART
  401 READ(5,FMT)ND,A4(1),(A4(I+1),I=1,NOCHNL)
      GO TO 600
  402 READ(5,FMT)ND,A6(1),(A6(I+1),I=1,NOCHNL)
C
  600 IF(ND.EQ.0) GO TO 618
  601 IF(ND.NE.ID) GO TO 620
C
C     CHECK TIME SEQUENCE OF CURRENT CARD
C
      IF(SWTCH2)  GO TO 602
      SWTCH2=.TRUE.
      GO TO 603
  602 IF((ABS(A4(1)-OLDT-DT)).GT.(DT*1.0E-01))  GO TO 630
  603 OLDT=A4(1)
C
C     STORE AND PRINT INPUT DATA
C
      GO TO(604,606),PART
C
  604 KS=KS+4
      STOR(KS)=A4(1)
      STOR(KS+1)=A4(2)
      STOR(KS+2)=A4(3)
      STOR(KS+3)=A4(4)
      IF(KS.LT.397)  GO TO 20
      WRITE(8) STOR
      KX=KX+1
      KS=-3
      IF(SWTCH1) GO TO 20
      WRITE(6,914)(STOR(I),STOR(I+1),STOR(I+2),STOR(I+3),STOR(I+200),
     1 STOR(I+201),STOR(I+202),STOR(I+203),I=1,197,4)
  914 FORMAT(1H ,F13.6,3F16.7,F20.6,3F16.7 )
      CALL HEADER
      WRITE(6,916)
  916 FORMAT(1H0,52X,24H DATA READ IN, CONTINUED / )
      GO TO 20
C
```

```
  606 KS=KS+6
      BUFF(KS)=A6(1)
      BUFF(KS+1)=A6(2)
      BUFF(KS+2)=A6(3)
      BUFF(KS+3)=A6(4)
      BUFF(KS+4)=A6(5)
      BUFF(KS+5)=A6(6)
      IF(KS.LT.595)  GO TO 20
      WRITE(4) BUFF
      KX=KX+1
      KS=-5
      IF(SWTCH1)  GO TO 20
      WRITE(6,915) (BUFF(I),I=1,300)
  915 FORMAT(1H ,F19.6,5F21.8)
      CALL HEADER
      WRITE(6,916)
      WRITE(6,915) (BUFF(I),I=301,600)
      CALL HEADER
      WRITE(6,916)
      GO TO 20
C
  620 INM=1
      GO TO 618
  630 INM=2
C
C     PRINT OUT LAST RECORD
C
  618 GO TO(704,706),PART
C
  704 IF(KS.LT.397) WRITE(8) STOR
      K=KX*100+(KS+3)/4
      IF(SWTCH1 .OR. KS.EQ.397) GO TO 619
      IF(KS-200)701,701,702
  701 WRITE(6,814)(STOR(I),STOR(I+1),STOR(I+2),STOR(I+3),I=1,KS,4)
  814 FORMAT(1H ,F13.6,3F16.7)
      GO TO 619
  702 WRITE(6,914)(STOR(I-200),STOR(I-199),STOR(I-198),STOR(I-197),
     1 STOR(I),STOR(I+1),STOR(I+2),STOR(I+3),I=201,KS,4)
      WRITE(6,814)(STOR(I-196),STOR(I-195),STOR(I-194),STOR(I-193),
     1 I=KS,393,4)
      GO TO 619
C
  706 IF(K4.LT.595)  WRITE(4) BUFF
      K=KX*100+(KS+5)/6
      IF(SWTCH1 .OR. KS.EQ.595) GO TO 619
      LST=MIN0(295,KS)
      WRITE(6,915) BUFF(1),BUFF(2),BUFF(3),BUFF(4),BUFF(5),
     1 (BUFF(J+5),J=1,LST)
      IF(KS.LT.301) GO TO 619
      CALL HEADER
      WRITE(6,916)
      WRITE(6,915) BUFF(301),BUFF(302),BUFF(303),BUFF(304),BUFF(305),
     1 (BUFF(J+5),J=301,KS)
  619 PART=PART+3
      IF(INM.EQ.0)  GO TO 970
```

```
C
C        ERROR MESSAGES
C
         GO TO (720,730),INM
   720   WRITE(6,10) ND,A4(1)
    10   FORMAT(1H0,17H WRONG ID NUMBER I10,F19.6)
         GO TO 635
   730   WRITE(6,11)ND,A4(1)
    11   FORMAT(1H0,19H CARD OUT OF ORDER I10,F19.6)
   635   READ(5,6)NOM
         IF(NOM.NE.0)  GO TO 635
         K=0
   970   CALL ETIMX(ITM,IETM,RETS)
         WRITE(6,975) IETM,RETS
   975   FORMAT(1H0,27H DIRECT DATA INPUT REQUIREDI4,5H MIN F4.1,4H SEC )
         RETURN
C
         END
```

M E M O R Y   M A P

SYSTEM, INCLUDING IOCS	00000 THRU 12123
FILE BLOCK ORIGIN	12132

NUMBER OF FILES - 8

1.	FTC03.	12132
2.	FTC04.	12155
3.	FTC08.	122C0
4.	FTC09.	12223
5.	S.FBIN	12246
6.	S.FBOU	12271
7.	S.FBPP	12314
8.	FTC10.	12337

OBJECT PROGRAM — 12362 THRU 5467C

1.	DECK '/FILES'		000C0
2.	DECK 'MAIN '	*	12362
3.	DECK 'GNTAPE'	*	14513
4.	DECK 'SUBCNT'	*	21147
5.	DECK 'TREAD '	*	21342
6.	DECK 'BACK '		21365
7.	DECK 'TYPE '		214C3
8.	DECK 'TYPEN '	*	21423
9.	DECK 'BBCD1 '		21474
10.	DECK 'HEADER'	*	21650
11.	DECK 'TODAY '		21750
12.	DECK 'ANGRAD'	*	21777
13.	DECK 'SPERT1'	*	22164
14.	DECK 'DAT650'		22446
15.	DECK 'PLOT '		22542
16.	DECK 'LINE '		240C3
17.	DECK 'SCAL '		24054
18.	DECK 'LSCALE'		24151
19.	DECK 'DXDY '		24257
20.	DECK 'AXIS '		24463
21.	DECK 'LCXDY '		24773
22.	DECK 'LAXIS '		25030
23.	DECK 'NUMBER'		25367
24.	DECK 'BCDFL '		25526
25.	DECK 'SYMBLJ'		25563
26.	DECK 'TIMX '		26317
27.	DECK 'ETIMX '		26327
28.	DECK 'MAXMIN'	*	26453
29.	DECK 'ID650 '		26573
30.	DECK 'SCA '		26620
31.	DECK 'UNLOAD'		271C6
32.	DECK 'SET '		27242
33.	DECK 'XEM '		27257
34.	DECK 'SMOOTH'	*	27514
35.	DECK 'REACT '	*	34302

36.	DECK	'DRAW '	*	40041
37.	DECK	'FREQ '	*	421C5
38.	DECK	'INPUT '	*	45222
39.	SUBR	'INSYFB'		000C0
40.	SUBR	'OUSYFB'		000C0
41.	SUBR	'POSTX '		47210
42.	SUBR	'PPSYFB'		000C0
43.	SUBR	'FPC '		47327
44.	SUBR	'F03 '		47330
45.	SUBR	'F04 '		47331
46.	SUBR	'F05 '		47332
47.	SUBR	'F06 '		47333
48.	SUBR	'F08 '		47334
49.	SUBR	'F09 '		47335
50.	SUBR	'F10 '		47336
51.	SUBR	'IOS '	*	47337
52.	SUBR	'RWB '		47636
53.	SUBR	'RWD '		50264
54.	SUBR	'ACV '	*	51202
55.	SUBR	'ECV '	*	51235
56.	SUBR	'FCV '	*	514C1
57.	SUBR	'GCV '		51733
58.	SUBR	'HCV '		52032
59.	SUBR	'ICV '	*	52157
60.	SUBR	'LCV '	*	52525
61.	SUBR	'OCV '	*	52576
62.	SUBR	'XCV '		527C4
63.	SUBR	'SLI '		52732
64.	SUBR	'SLO '		52755
65.	SUBR	'EFT '		530C0
66.	SUBR	'RWT '		53017
67.	SUBR	'FPT '		53036
68.	SUBR	'XIT '		53320
69.	SUBR	'XP1 '		53322
70.	SUBR	'XP2 '		53430
71.	SUBR	'XP3 '		53542
72.	SUBR	'XPN '		53633
73.	SUBR	'ATN '		53741
74.	SUBR	'LOG '		54155
75.	SUBR	'SCN '		54341
76.	SUBR	'SQR '		54573

(* - INSERTIONS OR DELETIONS MADE IN THIS DECK)

INPUT - OUTPUT BUFFERS	64714 THRU 74005
BLANK COMMON ORIGIN	74006
UNUSED CORE	54671 THRU 64672

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APPENDIX C -- SUPPLEMENTARY PROGRAMS

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```
C       FORTRAN ROUTINE TO PUT CARD DATA INTO SPORT TYPE-5 FORMAT.
C
C       REQUIRES SUBROUTINES TYPE,BCFX,BCDFL,UNLOAD AND THESE FILE CARDS
C
C       $FILE    'FTC03.',U03,U03,BLOCK=2022,DOUBLE,LRL=2021,RCT=0001
C       $ETC     EOR=REORX.,EOF=REOFX.,ERR=RERRX.,TYPE3
C       $FILE    'FTC04.',U04,U04,BLOCK=2022,DOUBLE,LRL=2021,RCT=C001
C       $ETC     EOR=REORX.,EOF=REOFX.,ERR=RERRX.,TYPE3
C
        DIMENSION STOR(2019),DATA(2000),FMT(14),DUMMY(10)
        EQUIVALENCE (STOR(15),KOUNT),(STOR(17),ID),(STOR(18),TO),
      1 (STOR(19),DT),(STOR(20),DATA)
C
C       READ CONTROL CARD
C
        READ(5,1) MOUNT,IREEL,ND,TSTART,DELTAT
      1 FORMAT(I2,I6,2X,I10,2E10.8)
C
C       IF MOUNT = 1, OPERATOR WILL MOUNT REEL 'IREEL' ON S.SU03.
C       IF MOUNT = 0, THIS DATA WILL BE FIRST ON THE OUTPUT TAPE.
C
C       THIS DATA WILL HAVE IDENTIFICATION NUMBER 'ND'. THE FIRST DATA
C       VALUE WILL BE AT 'TSTART' AND THE TIME INCREMENT BETWEEN SUC-
C       CESSIVE DATA VALUES WILL BE ASSUMED TO BE 'DELTAT'.
C
        REWIND 4
        ICONT=0
C
C       MOUNT PREVIOUS DATA TAPE (IF ANY) AND TRANSFER RECORDS TO S.SU04
C
        IF(MOUNT.EQ.0)  GO TO 5
        CALL TYPE(1H ,1,0)
        CALL TYPE(18H PLEASE MOUNT REEL,18,0)
        CALL BCFX(IREEL,IREEL2)
        CALL TYPE(IREEL2,5,0)
        CALL TYPE(38H ON S.SU03 AND PRESS START TO CONTINUE,38,1)
C
        REWIND 3
        WRITE(6,2) IREEL
      2 FORMAT(1H1,40H RECORDS TRANSFERRED TO S.SU04 FROM REELI5 //
      1 59H  FILE INDX  IDENTIFICATION NO    INITIAL TIME      DELTA T//)
C
      3 READ(3) STOR
        IF(ID.EQ.0)  GO TO 5
        KOUNT=ICONT
        WRITE(4) STOR
        WRITE(6,4) KOUNT,ID,TO,DT
      4 FORMAT(1H ,I7,I18,F20.6,F14.6)
        ICONT=ICONT+1
        GO TO 3
C
C       READ IN CARD FORMAT
C
      5 READ(5,6) IDATNO,FMT
      6 FORMAT(I1,13A6,1A1)
```

```
C
C     A NON-ZERO INTEGER IDENTIFICATION NUMBER MUST PRECEDE THE TIME
C     AND DATA VALUES ON EACH DATA CARD. IF THERE IS MORE THAN ONE
C     DATA VALUE PER CARD, 'IDATNO' IN COLUMN ONE MUST BE THE NUMBER
C     OF THE DATA TO BE USED. TO PICK UP THE SECOND DATA VALUE, ENTER
C     A TWO IN COLUMN ONE, ETC. THE FORTRAN FORMAT STATEMENT DESCRIB-
C     ING THE DATA SHOULD BE ENTERED (MINUS THE WORD FORMAT) SOMEWHERE
C     IN COLUMNS 2-80.
C
C     READ THE DATA CARDS
C
      ID=ND
      TO=TSTART
      DT=DELTAT
    7 DO 8 I=1,2000
      READ(5,FMT) ND,(DUMMY(J),J=1,IDATNO),DATA(I)
      IF(ND.EQ.0)   GO TO 10
    8 CONTINUE
      KOUNT=ICONT
      WRITE(4) STOR
      WRITE(6,9) KOUNT,ID,TO,DT,DATA
    9 FORMAT(1H0,I7,I18,F20.6,F14.6 // 12(1X,1PE10.3) )
      ICONT=ICONT+1
      TO=TO+2000.0*DT
      GO TO 7
C
C     ZERO OUT THE REMAINDER OF THE LAST RECORD
C
   10 DO 11 L=I,2000
   11 DATA(L)=0.0
C
      KOUNT=ICONT
      WRITE(4) STOR
      WRITE(6,9) KOUNT,ID,TO,DT,(DATA(L-1),L=2,I)
      READ(5,1) MOUNT,IREEL,ND,TSTART,DELTAT
      IF(ND.NE.0)   GO TO 5
C
C     EACH DATA DECK SHOULD BE FOLLOWED BY A BLANK CARD.
C     THE LAST DECK SHOULD BE FOLLOWED BY TWO BLANK CARDS.
C
C     WRITE TERMINAL RECORD WITH ZERO ID NUMBER AND CLOSE OUT S.SU04
C
   12 ID=0
      KOUNT=ICONT+1
      WRITE(4) STOR
      WRITE(6,9) KOUNT,ID
      END FILE 4
      CALL UNLOAD(4)
      STOP
C
      END
```

```
C       FORTRAN SUBROUTINE TO READ SMOOTH BINARY OUTPUT TAPES
C
C       IF THE FIRST ARGUEMENT IS NON-ZERO, THE DATA TAPE WILL BE CALLED
C       FOR AND THE RECORDS CONTAINING SMOOTHED DATA CORRESPONDING TO
C       IDENTIFICATION NUMBER 'ID' AND CHANNEL NUMBER 'ICHAN' (THE FIRST
C       TWO ARGUEMENTS) WILL BE LOCATED ON THE DATA TAPE.
C
C       SUBSEQUENT CALLS WITH ZERO IN THE FIRST ARGUEMENT WILL RETURN
C       WITH SUCCESSIVE VALUES OF TIME AND COEFFICIENTS C, B, AND A IN
C       THE LAST FOUR ARGUEMENTS.
C
C       REQUIRES SUBROUTINE TYPE AND THE FF FILE CARDS-
C
C       $FILE    'FTC04.',U04,U04,BLOCK=0401,DOUBLE,LRL=0400,RCT=0001
C       $ETC     EOR=REORX.,EOF=REOFX.,ERR=RERRX.,TYPE3
C
        SUBROUTINE GULP(ID,ICHAN,T,C,B,A)
C
        DIMENSION STOR(400)
        INTEGER CHNLNO
C
        IF(ID.EQ.0)  GO TO 100
C
C       MOUNT DATA TAPE
C
        CALL TYPE(1H ,1,0)
        CALL TYPE(26H MOUNT DATA TAPE ON S.SU04,26,0)
        CALL TYPE(1H ,1,0)
        CALL TYPE(24H PRESS START TO CONTINUE,24,1)
C
C       FIND RECORD
C
        REWIND 4
    2   READ(4) ND,CHNLNO,DT,K
        IF(ND.EQ.20000000002)  GO TO 20
        IF(ND.NE.ID)  GO TO 2
        IF(ICHAN.EQ.0 .OR. CHNLNO.EQ.ICHAN)  GO TO 10
        GO TO 2
C
C       SET UP INITIAL PARAMETERS
C
   10   IF(K.EQ.0)  GO TO 500
        NCR=(K-1)/100
        NMAX=4*K-NCR*400-3
        KR=397
        NRR=0
        RETURN
C
C       ERROR MESSAGE IF UNABLE TO FIND CORRECT CHANNEL
C
   20   WRITE(6,21) ID,ICHAN
   21   FORMAT(1H0,36H NO DATA WITH IDENTIFICATION NUMBER I10,20H AND CHA
       1NNEL NUMBER I1,13H ON DATA TAPE  )
        ID=ND
        RETURN
```

```
C
C       READ IN NEW DATA POINT.
C
  100   IF(ND.EQ.20000000002)  RETURN
        KR=KR+4
        IF(KR.LT.400)  GO TO 105
        IF(NRR.GT.NCR)  GO TO 500
        READ(4) STOR
        NRR=NRR+1
        KR=1
  105   IF(NRR.LE.NCR)  GO TO 106
        IF(KR.GT.NMAX)  GO TO 500
  106   T=STOR(KR)
        C=STOR(KR+1)
        B=STOR(KR+2)
        A=STOR(KR+3)
        RETURN
C
C       ERROR MESSAGE IF END OF DATA IS REACHED
C
  500   WRITE(6,501)
  501   FORMAT(1H0,37H END-OF-DATA ENCOUNTERED ON DATA TAPE )
        ID=20000000002
        ND=ID
        RETURN
C
        END
```

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